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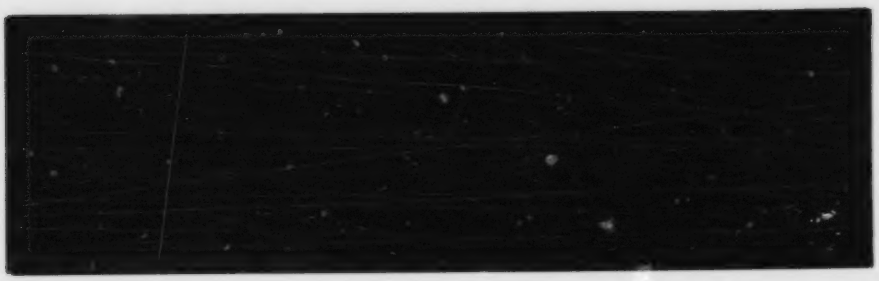

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ROCK PROPERTIES DATA BASE

R. Jackson, B. Gorski and M. Gyenge

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ROCK PROPERTIES DATA BASE

by

R. Jackson[1], B. Gorski[2] & M. Gyenge[3]

ABSTRACT

The mining industry in Canada requires increasingly more detailed information on both the pre- and post-failure support capabilities of rock especially as companys move into deeper and more highly stressed ground. The Rock Properties Data Base offers a summary of results for many rock types typical of Canadian mine environments. These results include values for: density, porosity, compressive and shear wave velocity, uniaxial compressive strength, Young's modulus and Poisson's ratio. More importantly, the data base contains m and s values determined using the Hoek and Brown failure criteria for both pre- and post-failure conditions. These are presented using detailed data sheets and summary tables.

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Keywords:
Rock Properties, Mechanical, Young's Modulus, Poisson's Ratio, Uniaxial Compressive Strength, Compressive Wave Velocity, Shear Wave Velocity, Hoek and Brown

BASE DE DONNÉES SUR LES PROPRIÉTÉS DES ROCHES

par

R. Jackson[1], B. Gorski[2] et M. Gyenge[3]

RÉSUMÉ

L'industrie minière au Canada a besoin de plus en plus d'information détaillée sur les capacités de soutènement de la roche avant et après rupture, notamment à mesure que les sociétés exploitent du terrain aux contraintes de plkus en plus élevées. La Base de données sur les propriétés des roches renferme un résumé de résultats pour un grand nombre de roches typiques des environnements miniers canadiens. Ces résultats comprennent des données telles que la masse volumique, la porosité, la vitesse des ondes de compression et de cisaillement, la résistance à la compression uniaxiale, le module d'Young et le coefficient de Poisson. Plus important encore, la base de données contient des valeurs de m et de s établies à l'aide du critère de rupture de Hoek et Brown, tant avant qu'après rupture. Ces données sont présentées dans des feuilles de données détaillées et des tableaux synoptiques.

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Mots clés:
Propriétés des roches, mécanique, module d'Young, Coefficient de Poisson, résistance à la compression uniaxiale, vitesse des ondes de compression, vitesse des ondes de cisaillement, Hoek et Brown

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ROCK PROPERTIES DATA BASE

INTRODUCTION

The search for ore has occupied mankind since the beginning of recorded history. Relatively little time passed, however, before ever-increasing demands exhausted surface mineral deposits and the mining industry (such as it was) was forced to begin underground excavation for new sources of ore. Unfortunately, the success or failure of these early forays into underground mine design was measured as much in terms of loss of life as in tonnage recovered. Gradually, though, mining became safer, more as a result of accumulated experience than from an understanding of underlying principles.

Today the industry is again faced with a similar dilemma with relatively shallow reserves quickly being depleted. Companies are having to proceed deeper and into areas whose stability is threatened by extremely high and complex stress fields. Consequently, both safety and economic concerns require that failure envelopes be more precisely and rigorously defined and the support capabilities of even failed material taken into consideration. The science of rock mechanics and its associated technologies have made great strides in recent years to answer the increasing needs for more specialized knowledge. The resources and necessary expertise required to determine the post-failure behaviour of rock, however, is often beyond the grasp of all but the largest mining companies.

In response, the Mining Research Laboratories division (MRL) of the Canada Centre for Mineral and Energy Technology (CANMET) has compiled a summary of the pre- and post-failure mechanical properties of rock types which were tested to provide design data for ground control programs within MRL and elsewhere. The Rock Properties Data Base presents these results in a single, concise and what is hoped easily understood volume. In addition, analysed results, established by the Mohr-Coulomb and Hoek and Brown failure criteria, are included for preliminary design purposes.

The data base, itself, is divided into three sections. The first is a general description of the test procedures used in determining the mechanical properties of the various rock types. This includes outlines of methods used for direct and indirect tensile testing, uniaxial compression testing and conventional, multi-stage, continuous failure state and extension triaxial testing.

Mechanical rock property characterization is an on-going activity at MRL and, as such, new data is constantly being generated. Consequently, the data base is updated on an annual basis to include the results of programs which have been conducted during the previous year. The first appearance of results includes a detailed data sheet such as that shown in Figure 1. The sheet contains, when available, information under the following headings:

- **Origin**: the site from which the samples were obtained.

- **Reference No.**: the number(s) of the referenced report(s), listed in Table 3, from which the data sheet was assembled. The original report will generally contain the most detailed

Figure 1: Example of a detailed data sheet

Origin	Reference No.	Rock Type

Regional Geology	Structural Characteristics
	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)

	Hoek and Brown Material Constants						
	Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude:
Longitude:

information on the specific rock type being considered.

- **Rock Type**: the rock types have been named according to the classification system developed by the Colorado Schools of Mines which is summarized in Appendix A (Travis, 1955). This system identifies rock types solely in terms of petrography and while this may not be universally accepted, it does represent a reasonably unified approach for effective communication.

- **Regional Geology, Structural Characteristics**: these refer to the gross characteristics supplied by the on-site personnel on the formation from which the samples were obtained.

- **Petrography**: the petrographic analysis of the rock type in question.

- **Mechanical Properties**: summarized here are the uniaxial mechanical properties of the rock including bulk density, γ_d, porosity, n, specimen diameter, ϕ, specimen length, l, compressive wave velocity, V_p, shear wave velocity, V_s, uniaxial compressive strength, Q_u, tensile strength, σ_t, 50% tangent Young's modulus, E, Poisson's ratio, ν and the confining pressure range over which testing was conducted.

- **Hoek and Brown Material Constants**: includes m, s, r^2, m_r, s_r and r_r^2 values for the intact and residual strength conditions, respectively, as well as the uniaxial compressive strength, Q_c predicted by the model.

- **Borehole Information**: this includes the collar elevation, its depth, the inclination of the borehole and its latitude and longitude.

Finally, the data sheets contain a plot of the mean Mohr-Coulomb circles and the corresponding intact and residual strength failure envelopes determined using the Hoek and Brown failure criteria.

Following the initial publication of the data sheets, results described in them will, in subsequent years, be summarized in the third section of the report. This includes tabularized summaries of all the mean mechanical properties established to date arranged in alphabetical order according to rock type.

Table 1 contains the mean values of the mechanical properties determined for each rock type. These include its origin, the reference number and corresponding data sheet for more detailed information, bulk density, tensile strength, uniaxial compressive strength, Young's modulus, Poisson's ratio, compressive wave velocities (both saturated and dry) and porosity.

Table 2 summarizes the Hoek and Brown constants m, s, r^2, m_r, s_r and r^{2r} for both intact and residual conditions. For comparison, the actual and predicted uniaxial compressive strengths, Q_u and Q_c respectively, have been included.

As mentioned earlier, Table 3 is the list of references which contain detailed test program summaries, methodologies, results (complete with stress/strain histories) and observations and conclusions related to the test objectives. These may be obtained through MRL

by quoting the appropriate title and report number.

TEST METHODS

The scope and sophistication of the tests available to the mine engineer has increased dramatically over the last number of years. This has been due largely to the introduction of computer-controlled, servo-hydraulic compression machines such as the one shown in Figure 2.

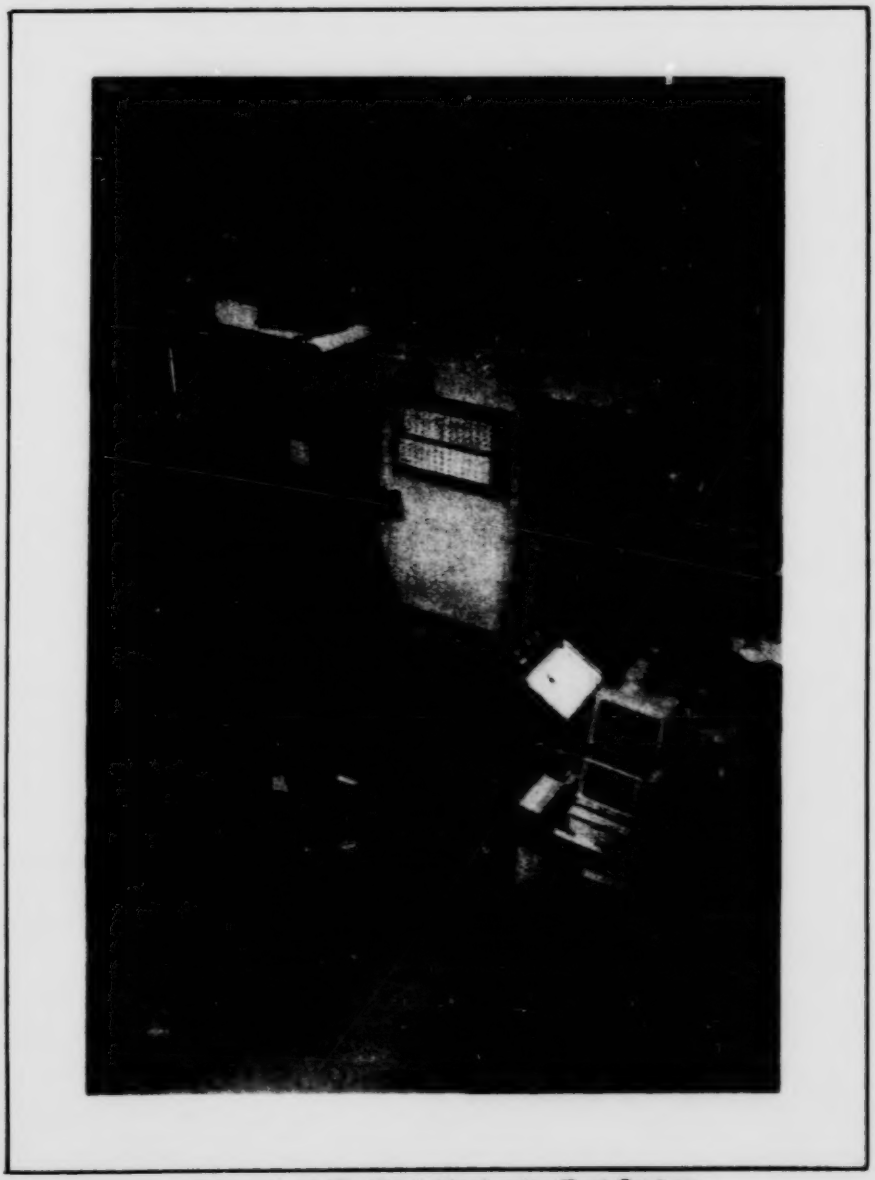

Figure 2: CMTL Rock Mechanics Test System

These new technologies allow investigators, to quickly adjust and readjust test conditions with great precision. As a consequence, methods such as multi-stage and continuous failure state testing have been developed to enable more information to be extracted from a single sample than was previously possible. In addition, servo-hydraulics give us the capability to determine post-failure properties of rock and avoid the violent, brittle fracture usually associated with softer, manually-controlled machines. The following, then, is a general overview of the test types available at MRL and how they have been used to acquire the data summarized in this report.

Tensile Strength

It has been shown that for several types of rock tested in compression, failure is often the result of tensile forces generated in the specimen. It becomes important, therefore, to get some estimate of tensile strength especially when complex stress conditions such as those surrounding deep underground openings are anticipated.

Direct tensile test: Direct measurement of the tensile strength is obviously the method of choice but problems caused by misalignment when gripping the specimen can result in the development of bending forces within the rock. Great care has to be taken that the axis of loading coincides with the specimen axis.

For average strength rocks, satisfactory results have been obtained using the plate and glue methods. The specimen is glued to two end loading caps which, in turn, are tensioned with suitable loading mechanisms (i.e. cable, chain, spherically seated joints etc.) (Figure 3, Fairhurst, 1961). For higher strength rocks both Hoek (1964) and Brace (1963) found that rock specimen machined down to a shape similar to that used for testing metals yielded good results.

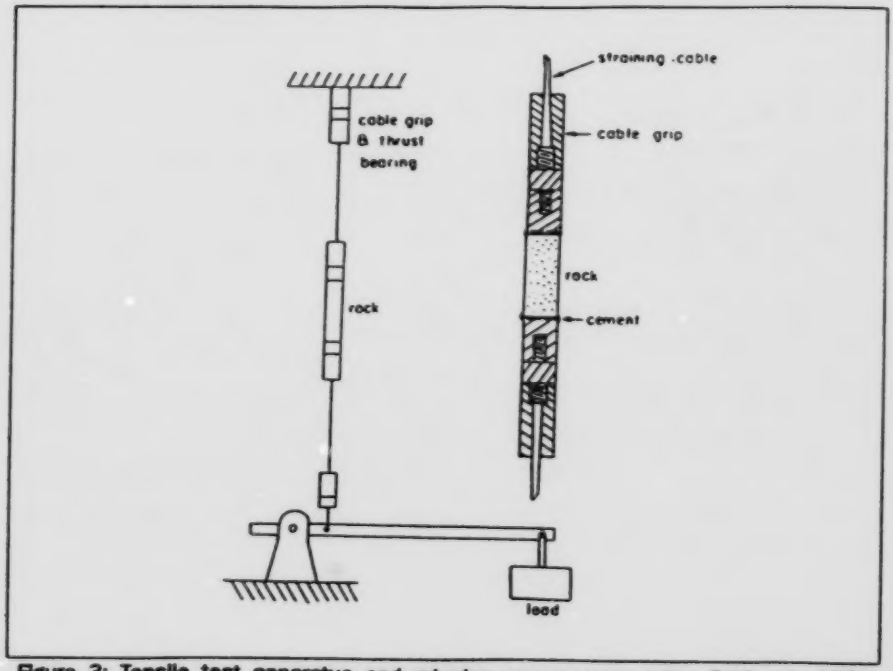

Figure 3: Tensile test apparatus and gripping arrangement (after Fairhurst, 1961)

While direct methods for determining tensile strength are preferable, the complexity of sample preparation and care required for testing make them unsuitable for many engineering investigations. Indirect methods often provide adequate estimates with a minimum of trouble. Two such methods used extensively at MRL include Brazilian tensile and bending or flexural tests.

Brazilian tensile test: This test employs a solid circular disc which is compressed to failure along its diameter. It can be shown that the horizontal stress perpendicular to the axis of loading is uniform and tensile (Figure 4).

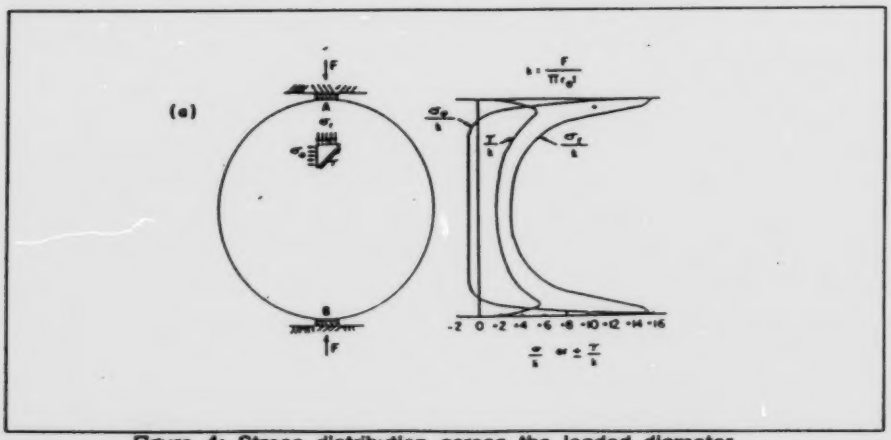

Figure 4: Stress distribution across the loaded diameter of a Brazilian test specimen (after Shook, 1963)

While Brazilian testing is, perhaps, the most convenient method of determining tensile strength, some care must be taken with its use. Short fissures which tend to lower the tensile strength when determined directly, do not have as pronounced an effect on splitting tension. Estimates made using the Brazilian test, therefore, can result in somewhat higher tensile strength than the actual values.

Bending or flexural test: A beam (prismatic or cylindrical), when subjected to bending develops tensile stresses along its convex surface and compressive stresses along its concave surface (Figure 5). As such, failure in tension can be anticipated and the tensile strength estimated from simple beam theory.

Again, caution is advised in using the results of bending tests. Some fundamental assumptions used in the analysis require that the material be homogeneous and the stress/strain behaviour be the same in both tension and compression. These obviously do not hold entirely true for rock and the flexural strength is often two to three times the tensile strength determined by direct methods. Some deviation also exists due to the relatively small volume of rock failed in pure tension in a flexed beam.

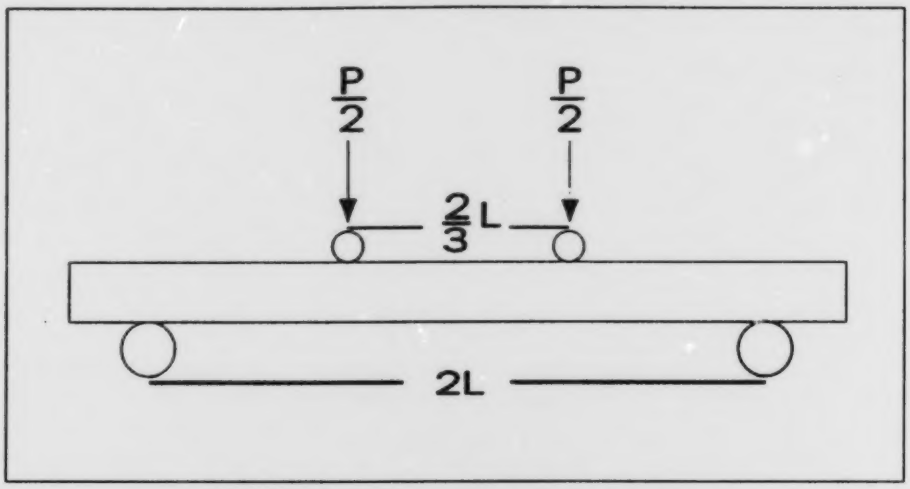

Figure 5: Bending or flexural test schematic

Uniaxial Compressive Strength

Testing in the post-failure region has, historically, been conducted using very stiff testing machines which minimized the transfer of stored strain energy from the load frame to the specimen at the point of failure. The entire stress/strain curve is then readily obtained for Class 1 rocks (Figure 6) where axial strain increases monotonically throughout the loading cycle (i.e. σ or ε = constant * time). It is not so easily achieved, however, for borderline Class 1/Class 2 and Class 2 rock types (idealized in Figure 7) where the control signal becomes unstable shortly after point A is reached causing violent failure.

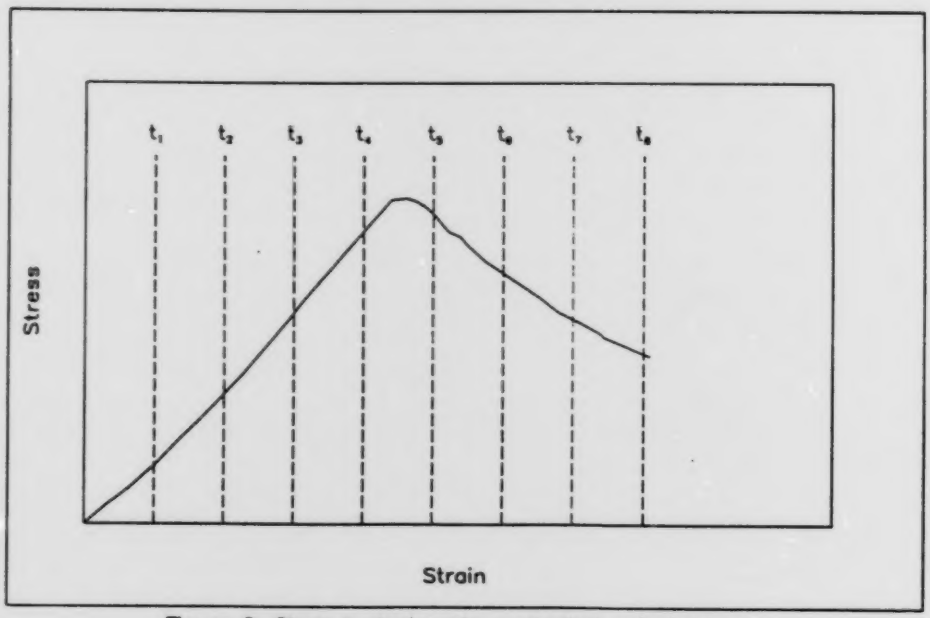

Figure 6: Class 1 strain rate controlled uniaxial test

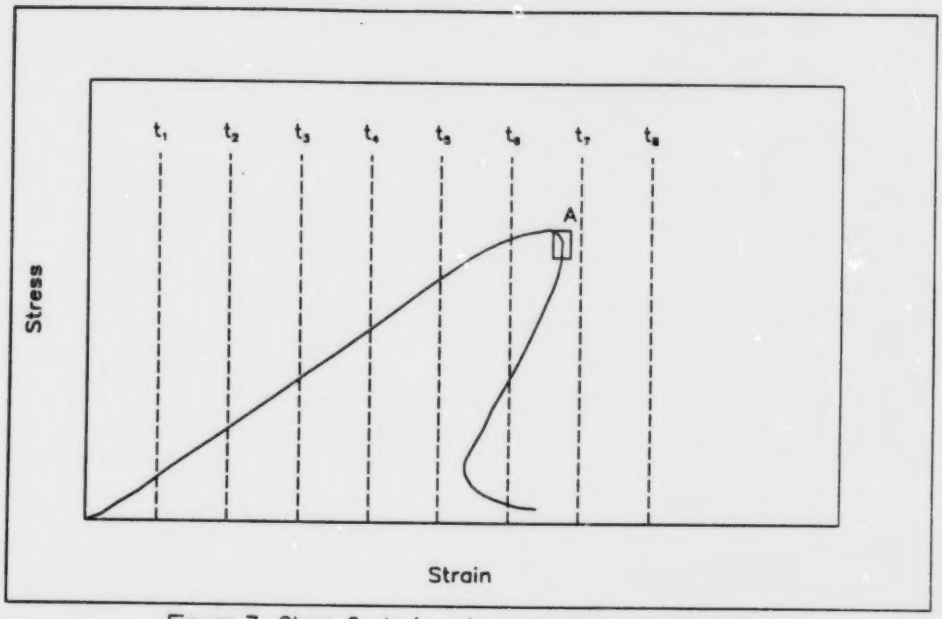

Figure 7: Class 2 strain rate controlled uniaxial test

The last two decades has seen the refinement of servo-control mechanisms which, when connected to the hydraulics of a frame actuator, enables loading to be controlled according to a number of chosen analogue outputs. This, coupled with increasingly sophisticated computer control, has allowed investigators to study post-failure of Class 2 rocks using such properties as lateral strain, inelastic strain and acoustic emission as control signals.

MRL has experimented with three different methods of determining post-failure behaviour. These include using axial stroke, lateral strain and a modified axial strain signal as control modes.

Axial strain control mode: For Class 1 rock, the entire pre- and post-failure stress/strain curve can be obtained using a single constant axial strain rate which is maintained throughout the loading sequence. To obtain post-failure behaviour for Class 2 rock, however, energy must be extracted from the system at ultimate strength to avoid violent failure.

This has been accomplished at MRL by monitoring, every second, the load required to maintain a specified axial strain rate. If the current load is equal to or less than the previous load reading (indicating imminent failure) then a command signal immediately causes the specimen to be unloaded to 60% of the last load level. The loading sequence is then re-initiated according to the originally specified strain rate. This pattern is repeated until an outline of the entire stress/strain curve can be traced using the maxima of each individual loading cycle (Figure 8).

Lateral strain control mode: Lateral or circumferential strain provides a convenient means of control for post-failure testing since it increases monotonically throughout the loading range for both Class 1 and 2 rock types. Feedback from a suitable transducer (i.e. a bicycle chain extensometer) enables computer-controlled servo-valves to either increase or decrease the load to maintain a constant lateral strain rate.

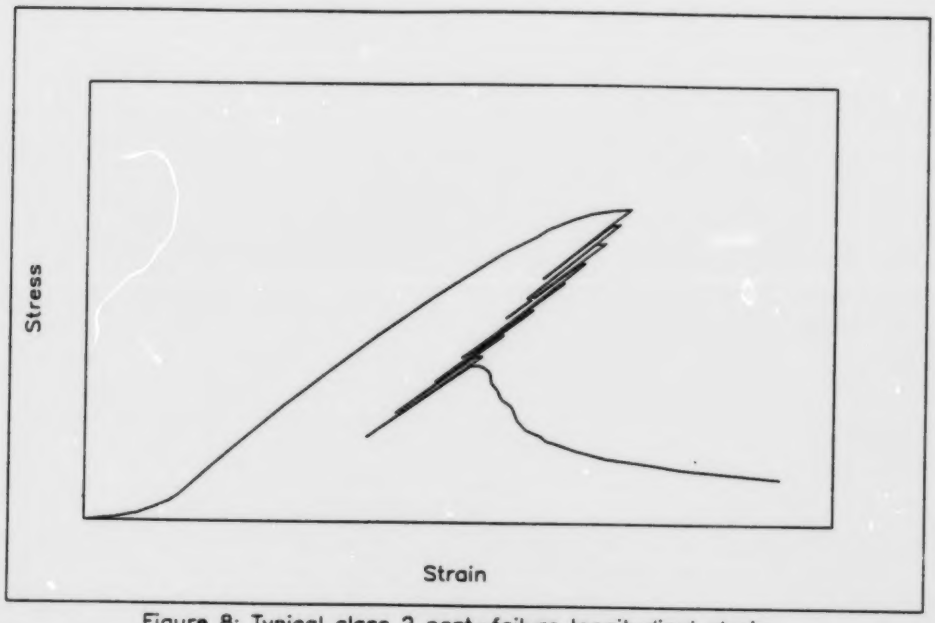

Figure 8: Typical class 2 post-failure longitudinal strain rate controlled uniaxial test

Unfortunately, crack formation in certain rock types causes the lateral strain to increase significantly just prior to failure. To compensate, the loading rate must be decreased, often to levels where visco-elastic or 'creep' effects may begin to occur. This can result in decreases in apparent strength and modulus values determined at failure.

Modified axial strain mode: Okubo and Nishimatsu (1985) controlled the failure of Class 2 rocks by modifying the axial strain according to the equation;

$$e - \frac{\sigma}{E'} = constant * time$$

E' represents an arbitrary modulus value which lies somewhere between the expected pre- and post-failure moduli for the rock type in question. 1/E' or the 'gain' alters the signal in such a way as to allow control throughout the post-failure region even if the post-failure modulus is positive (Figure 9).

Triaxial Compressive Strength

Perhaps the greatest impact of computer-controlled servo-hydraulics has been felt in the area of triaxial compression testing. The ability to quickly and accurately adjust the confining pressure and loading rate applied to a sample enables the investigator to utilize a number of unconventional stress paths which are not possible with standard compression machines. So while the traditional single confining pressure triaxial test remains a staple fixture for rock mass characterization, the development of techniques such as multi-stage and continuous failure state testing has extended the range of information available from each sample.

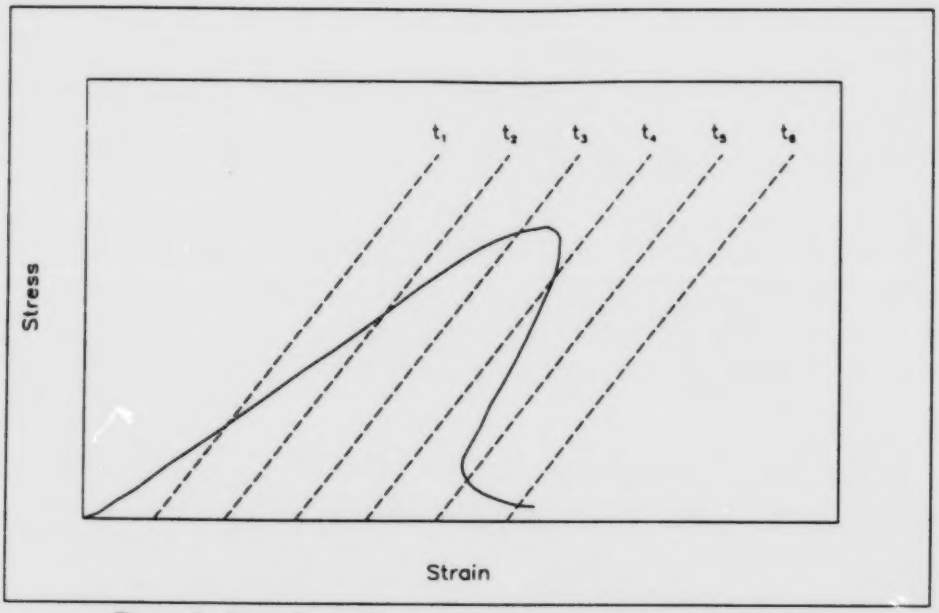

Figure 9: Class 2 modified strain rate controlled uniaxial test

Conventional triaxial test: In a conventional triaxial test, the specimen is loaded hydrostatically, generally by the simultaneous application of axial load and side pressure, to the desired confining pressure level. Axial loading then continues to failure according to the chosen control mode (i.e. load, axial strain, lateral strain etc.). Post-failure behaviour can be determined using any of the methods mentioned for uniaxial testing as long as the same caveats are observed.

Multi-stage triaxial test: Before testing begins, the confining pressures required to adequately describe a rock type's failure envelope for the anticipated ground conditions are determined by the investigator. The sample is then loaded hydrostatically to the lowest pre-determined confining pressure. It is subsequently loaded axially according to the control mode chosen prior to testing.

As in post-failure uniaxial testing, the load is monitored every second until the current load reading is equal to or less than the previous reading indicating the onset of failure. At this point, the confining pressure is immediately increased to the next level and loading continues. This process is repeated for each of the specified confining pressure until the maximum level is reached. Loading can then proceed into the post-failure region by any of the methods outlined for uniaxial testing. The residual strength, indicated by a plateauing of the stress/strain curve, can also be obtained for each of the lower confining pressures. This is accomplished by switching load control from the current mode to one which will maintain a specified axial displacement rate. The confining pressure is then reduced to the next lowest level and the stress/strain curve allowed to once again plateau out. This is repeated sequentially until the residual strength has been established for all desired confining pressures.

Continuous failure state test: The continuous failure state test is, essentially, a multi-state test where very little time elapses between an incremental increase in confining pressure and the corresponding onset of failure. This is accomplished by setting the confining pressure steps sufficiently small that only minimal additional loading is required to continue failing the specimen.

The main advantage of continuous failure state testing is that the resulting confining pressure vs failure stress curve is, in essence, a failure envelope for the specimen being tested.

Extension test: The vast majority of mine design is based on failure envelopes developed using the Griffith and Mohr-Coulomb criteria or modifications thereof. It has been shown, however, that, in brittle rock, slabbing of excavation walls has occurred at stress levels significantly less than those predicted by either model. It is also apparent from the orientation and condition of the observed fracture surfaces that failures have resulted in tensile rather than shear displacements. Stacey (1981) noted that failure in these materials can be caused by extensional strains arising from the Poisson's ratio effect.

Unsupported underground excavation results in a reorientation of local stress fields and, depending on tunnel configuration, can cause a reduction in confinement in some areas and stress concentrations in others. Under suitable conditions of compressive stress and reduced confinement, sufficient extension straining can occur to cause in extension fracturing. Since this type of failure occurs at stress levels considerably less than traditionally predicted values, it is important to find a method of estimating the stress conditions which can result in extensional failures.

At MRL, this is accomplished by hydrostatically loading a specimen to the major principle stress anticipated for a particular ground condition and tunnel configuration. The axial load is then held constant and the confining pressure reduced such that a constant rate of longitudinal strain is maintained. The onset of extensional strain failure is indicated by a plateauing of the confining pressure versus axial strain curve.

Multi-stage extension test: For multi-stage extension testing, the specimen is loaded hydrostatically to the highest pre-determined stress level. As in the single stage test, the confining pressure is reduced according to a specified axial strain rate until the onset of failure. As the specimen begins to fail, the axial load is reduced to the next lower stress level of interest. The confining pressure is again reduced as described earlier. This sequence is repeated until all predetermined stress levels have been investigated.

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Data Sheet 1

Origin	Reference No.	Rock Type
Montauban Mine, Quebec	2	amphibolite

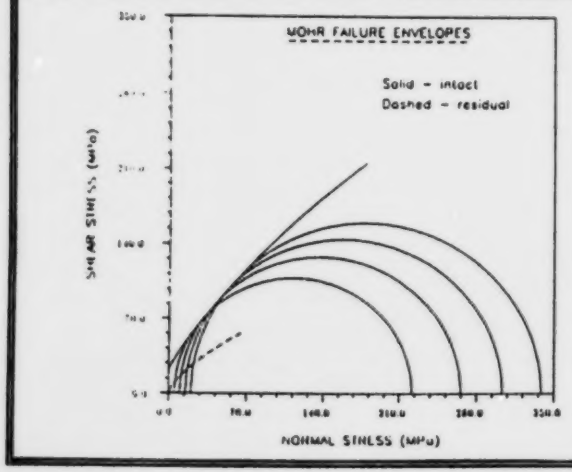
Regional Geology	Structural Characteristics
Precambrian rock in the Grenville Province/Series metavolcano-sedimentary rocks	Dip: Strike: NW-SE (orebody) Bedding Thickness: variable Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting : Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.90		46	91							5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
170.06	21.36	1.00	1.00	3.05	0.00	0.66

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 55'
Longitude: 72° 10'

Data Sheet 2

Origin	Reference No.	Rock Type
Chimo Mine, Quebec	19	andesite

Regional Geology

upper Malartic Group, in the Abitibi Greenstone Belt of the Superior Province (Archean Age), W-NW belt of metasediments with contact metavolcanics at North

Structural Characteristics

Dip: 70° to 80°
Strike: 135°
Bedding Thickness: 7.6m
Fracture Spacing: 5-30cm
Weathering: none

Petrography

Structure:

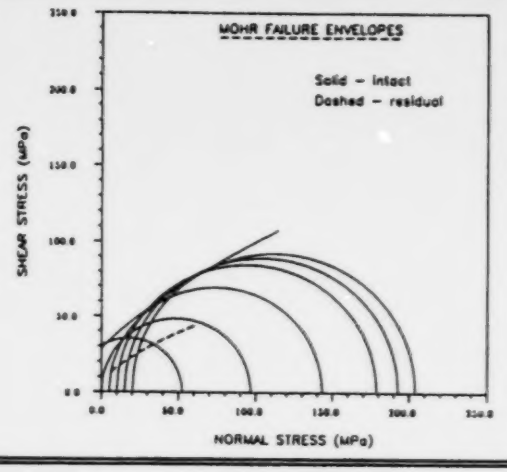
Texture: Grain Size:
Colour:
Grain Sorting:
Grain Shape:
Matrix:

Composition

carbonates, basic minerals, quartz, corundum

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.80		46	91			96.70	-17.50	55.82	0.31	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
128.13	6.67	1.00	0.89	2.59	0.12	0.22

Borehole Information

Collar Elevation:
Depth: 36.9m
Inclination: -90°
Latitude: 48° 2' N
Longitude: 77° 10' W

Data Sheet 3

Origin	Reference No.	Rock Type
Hislop Township, Quebec	3	andesite

Regional Geology

Archean, part of the Abitibi Greenstone Belt, massive rock, with carbonate throughtout

Structural Characteristics

Dip: 75° to 80° NW
Strike: NW-SE generally
Bedding Thickness:
Fracture Spacing:
Weathering:

Petrography

Structure: smooth, undulating joints with calcite infilling

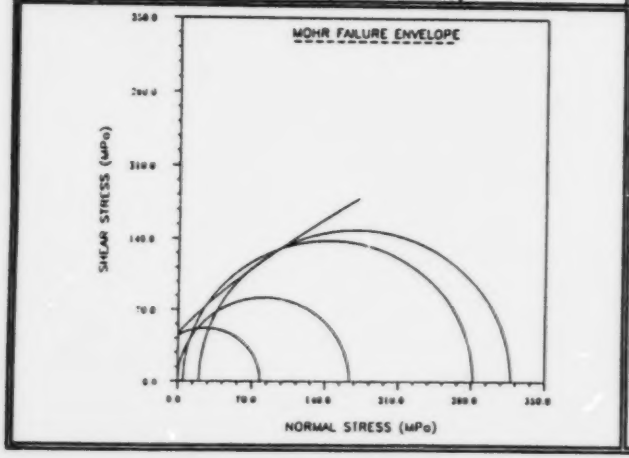
Texture: Grain Size: medium to fine
Colour: medium to dark grey
Grain Sorting:
Grain Shape:
Matrix:

Composition

1% pyrite

Mechanical Properties

γ_d (Mg/m³)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.90	<0.1	46	91	5.90		163.47	-25.96	73.21	0.28	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
226.12	7.75	1.00	0.79			

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 30' N
Longitude: 80° 15' W

Data Sheet 4

Origin	Reference No.	Rock Type
Hislop Township, Ontario	3	breccia

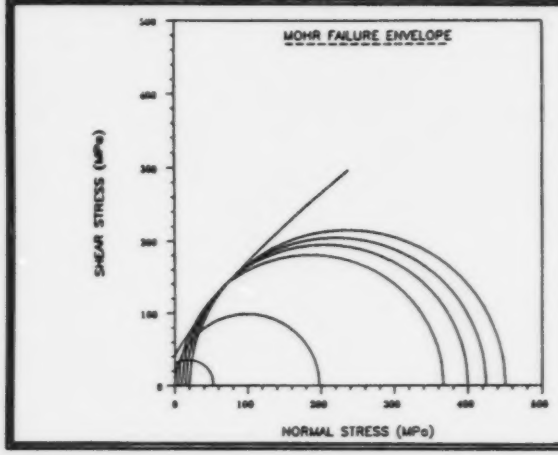
Regional Geology	Structural Characteristics
Archean, part of the Abitibi Greenstone Belt	Dip: 75° to 80° NE Strike: NW-SE generally Bedding Thickness: 7.6-30.5m Fracture Spacing: Weathering:

Petrography

Structure: massive	Composition
Texture: Grain Size: 1.6-25.4mm Colour: medium to dark grey Grain Sorting: Grain Shape: angular to subangular Matrix: grey-coloured	chlorite, carbonates, silicates 1-10% pyrite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.89		46	91			197.63	-17.72	87.22	0.26	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
291.86	17.89	1.00	0.89			

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 30' N
Longitude: 80° 15' W

Data Sheet 5

Origin	Reference No.	Rock Type
Lingan Mine, Cape Breton	7	coal

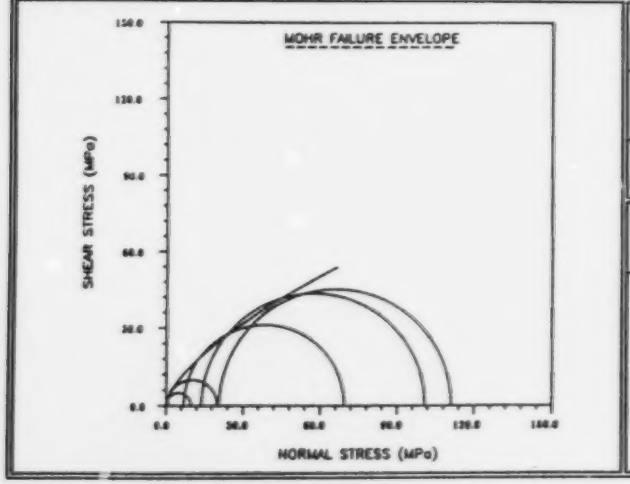
Regional Geology	Structural Characteristics
Morien Group, Glace Bay Sub-basin of the Carboniferous Sydney Basin	Dip: 4° to 15° seaward Strike: E-NE Bedding Thickness: 2.3m Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
1.24		46	91			9.78	-0.43	1.76	0.34	0.3-20.7



Hock and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
20.96	20.26	1.00	0.95			

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 60° 5' W

Data Sheet 6

Origin	Reference No.	Rock Type
Pamour Mine, Ontario	20	conglomerate

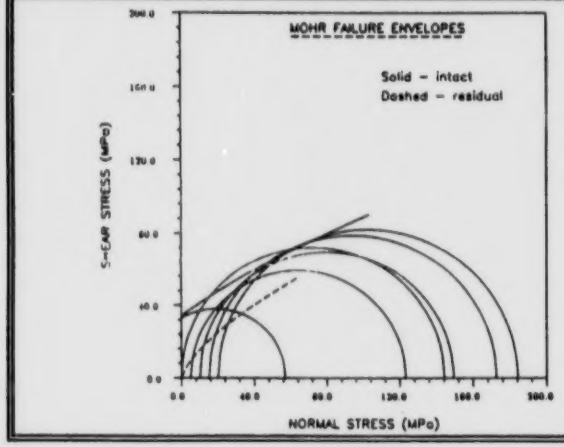
Regional Geology	Structural Characteristics
mineralized zone, north of the Destor-Porcupine Fault; close to the contact of sedimentary and volcanic rocks of the Superior Province	Dip: 70° to 80° N Strike: 270° W Bedding Thickness: 10.4m Fracture Spacing: <5cm to 1m Weathering: little to none

Petrography

Structure: tight joints, rough planar and undulated surfaces	Composition
Texture: Grain Size: variable Colour: Grain Sorting: Grain Shape: rounded Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.76		46	91			144.28	-18.97	64.41	0.25	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
126.36	4.07	1.00	0.84	3.51	0.00	0.24

Borehole Information

Collar Elevation:
Depth: 9.0m (to conglomerate)
Inclination: -64° S
Latitude: 48° 30' N
Longitude: 81° 20' W

Data Sheet 7

Origin	Reference No.	Rock Type
Creighton Mine, Ontario	6	norite

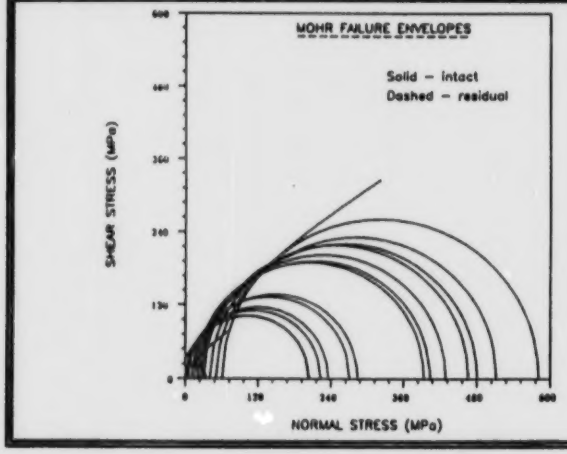
Regional Geology	Structural Characteristics
Huronian Supergroup, Elliot Lake Group, Copper Cliff Formation, Precambrian Rocks, southern rim of the norite deposit, in the Sudbury Basin	Dip: Strike: 75° SW Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: tight, unaltered joints; uniform, rough to smooth joint surfaces	Composition
Texture: Grain Size: coarse Colour: dark Grain Sorting: Grain Shape: Matrix: uniform	50-60% labradorite, 18-30% ferromagnesians - hornblende and biotite, <5% sulphide minerals, called "norite" due to An content, quartz

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
3.03		55	109			203.40	-11.53	59.74	0.18	2.0-60.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
222.67	17.14	1.00	0.95	5.40	0.04	0.49

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 25' N
Longitude: 81° 20' W

Data Sheet 8

Origin	Reference No.	Rock Type
Lac St Jean, Quebec	9	diabase, fine grained

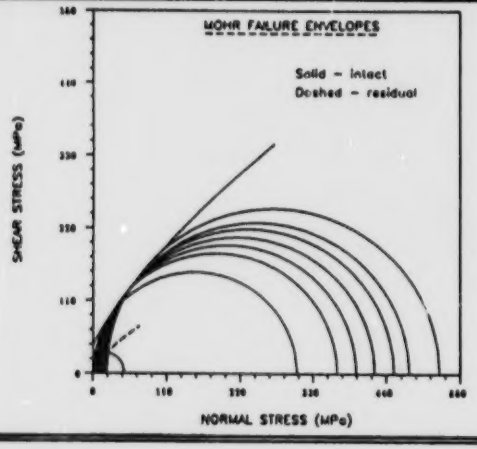
Regional Geology	Structural Characteristics
intrusive diabase dike	Dip: Strike: Bedding Thickness: Fracture Spacing: none Weathering: none

Petrography

Structure: homogeneous, unmetamorphosed aphanitic; massive	Composition
Texture: Grain Size: fine Colour: dark-greyish dark Grain Sorting: Grain Shape: Matrix:	56% light brown plagioclase, 44% pale brown augite, actinolite, biotite, prehnite, quartz, opaque minerals

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.97	<0.1	42	84	5.34		306.00	-15.69	89.54	0.30	3.5-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
321.27	20.40	1.00	0.99	3.03	0.00	0.81

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 30'N
Longitude: 71° 45'W

Data Sheet 9

Origin	Reference No.	Rock Type
Eldrich Mine, Quebec	10	diorite

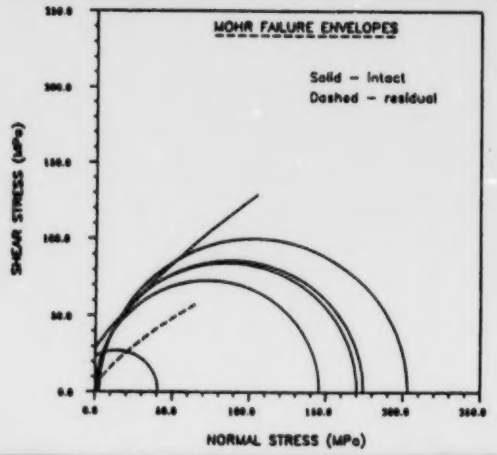
Regional Geology	Structural Characteristics
southern volcanic zone of the Abitibi greenstone belt altered rocks from the NW sector of the Flavrian batholith Blake River Group, Archean age, also called Eldrich gabbro, results of incomplete mixing of 2 magmas in a turbulent region	Dip: 30° to 45° Strike: 30° SE Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: homogeneous, primary ophitic	Composition
Texture: Grain Size: fine Colour: grey-green Grain Sorting: Grain Shape: Matrix:	40-50% plagioclase (saussuritized), 35-45% hornblende 3-15% quartz, accressory minerals: albite, sericite, calcite, chlorite, sphene, opaques

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.85	0.15	46	91	6.62		143.13	-13.57	79.86	0.29	1.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
165.47	11.45	1.00	0.88	3.86	0.01	0.28

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 19' N
Longitude: 79° 11' W

Data Sheet 10

Origin	Reference No.	Rock Type
Montauban Mine, Quebec	2	quartz-mica-biotite gneiss

Regional Geology

precambrian rocks in the Grenville Province/Series metavolcano-sedimentary rocks

Structural Characteristics

Dip:
Strike: NW-SE (orebody)
Bedding Thickness:
Fracture Spacing:
Weathering:

Petrography

Structure: well developed gneissic banding

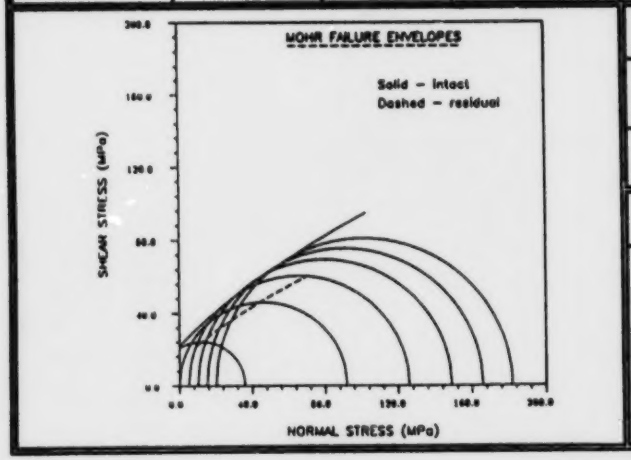
Texture: Grain Size:
Colour:
Grain Sorting:
Grain Shape:
Matrix:

Composition

50-70% quartz, 30-50% muscovite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.75		46	91			93.17	-12.00	41.72	0.25	5.0-20.00



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
103.21	7.57	1.00	0.98	4.78	0.40	0.01

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 55'
Longitude: 72° 10'

Data Sheet 11

Origin	Reference No.	Rock Type
Montauban Mine, Quebec	2	quartz-biotite gneiss

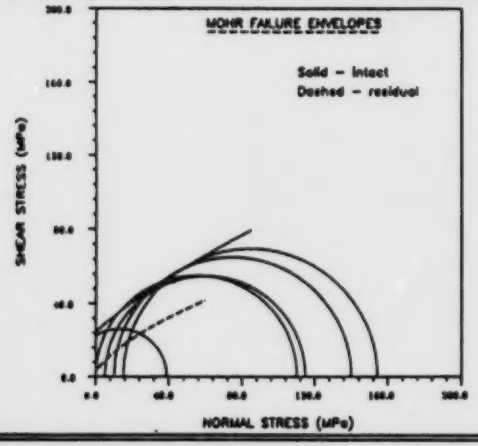
Regional Geology	Structural Characteristics
precambrian rocks in the Grenville Province/Series, metavolcano-sedimentary rocks	Dip: Strike: NW-SE (orebody) Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: well developed gneissic banding	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	50-70% quartz, 30-50% biotite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.69		46	91			110.28	-12.97	40.99	0.49	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
103.20	5.68	1.00	0.97	2.27	0.02	0.33

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 55'
Longitude: 72° 10'

Data Sheet 12

Origin	Reference No.	Rock Type
Blue Beach North, Newfoundland	4	pink granite

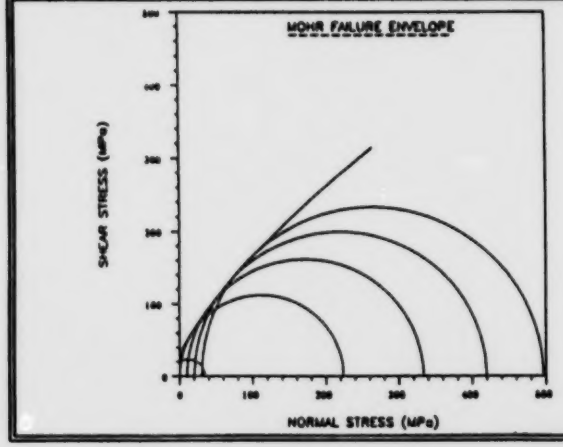
Regional Geology	Structural Characteristics
St. Lawrence granite, Devonian, also called Red Alaskite, from a Carboniferous pluton, host rock for fluorite veins	Dip: generally steep to the West Strike: 135° Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: porphyritic	Composition
Texture: Grain Size: medium to coarse; phenocrysts up to 1cm diameter Colour: pink Grain Sorting: Grain Shape: Matrix:	30-60% alkali feldspar, 20-40% quartz, 0-20% albite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.55	1.43	38	76	5.17		223.86	-11.53	63.61	0.27	10.0-30.0



Hock and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
236.87	22.10	1.00	1.00			

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 55'
Longitude: 55° 23'

Origin	Reference No.	Rock Type
Pinawa, Manitoba	11	granite, pink and grey

Regional Geology

Originates from the Lac Du Bonnet Batholith (Archean Age) in the Englis River Subprovince, pink colour caused by submicroscopic iron-oxide coatings and fillings, from hydrothermal fluids

Structural Characteristics

Dip: 50-55° N
Strike:
Bedding Thickness: 137-400m
Fracture Spacing: 2-22m
Weathering:

Petrography

Structure: massive, porphyritic, few fractures, medium-coarse grained

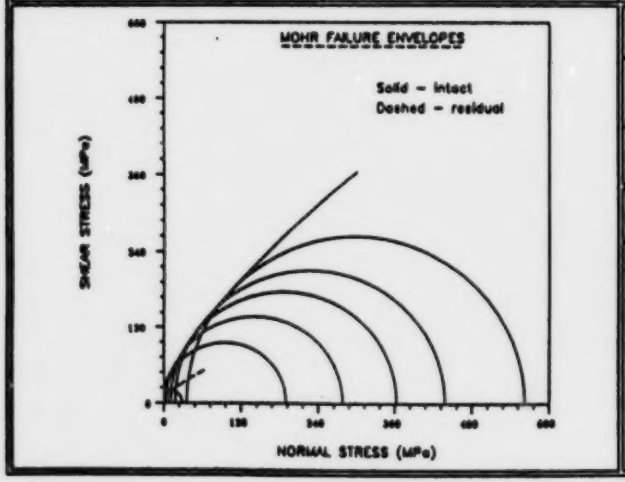
Texture: Grain Size: microscopic to 20mm
Colour: grey, pink
Grain Sorting:
Grain Shape:
Matrix:

Composition

plagioclase (oligoclase) 37.5%, microcline 27.3%, quartz 30.6%, biotite 3.5%, muscovite 0.5%, sphene, apatite, calcite, epidote, iron oxide, allanite 0.6%

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.63	0.36	44	98	4.43		190.00	-9.56	65.30	0.27	3.5-35.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
234.15	27.75	1.00	0.99	2.26	0.00	0.97

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 50° 25' N
Longitude: 96° 00' W

Data Sheet 14

Origin	Reference No.	Rock Type
Belmoral Mine, Quebec	17	granodiorite

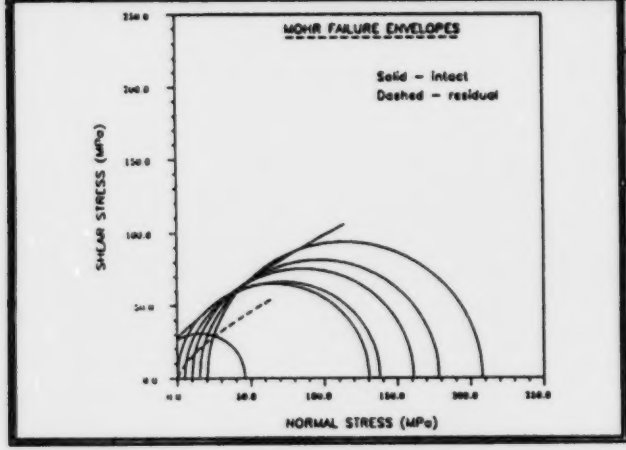
Regional Geology	Structural Characteristics
Bourlamaque batholith, cutting the Malartic Group in the Abitibi Greenstone Belt of the Superior province (Archean age)	Dip: 65° SE Strike: 70° Bedding Thickness: 5.2m Fracture Spacing: 30cm to 1m Weathering: none

Petrography

Structure: cross-jointed, vertical joints, unaltered, smooth planar to slickenside joint surfaces	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	feldspar, hornblende, altered diorite, quartz, some hematitic and sericitic alteration

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.78	0.22	46	91	6.06		130.37	-15.13	69.47	0.28	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
125.37	6.64	1.00	0.97	3.64	0.00	0.15

Borehole Information

Collar Elevation:
Depth: 19.2m
Inclination: -90°
Latitude: 48° 8' N
Longitude: 77° 38'W

Data Sheet 15

Origin	Reference No.	Rock Type
Pamour Mine, Ontario	20	greywacke

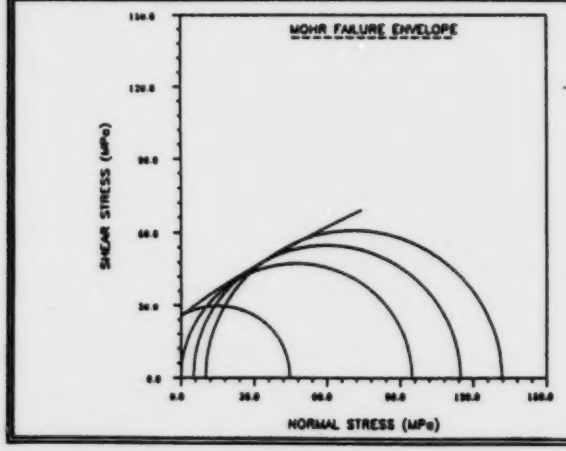
Regional Geology	Structural Characteristics
north of the Destor-Porcupine Fault; close to the contact of sedimentary and volcanic rocks of the Superior Province	Dip: 70° to 80° N Strike: 270° W Bedding Thickness: 3.4m to 9.1m Fracture Spacing: <5cm to 30cm Weathering: slight

Petrography

Structure: tight, closely spaced joints, smooth to rough planar surfaces	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.76		46	91			134.10	-14.89	44.20	0.29	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
99.14	4.49	1.00	0.98			

Borehole Information

Collar Elevation:
Depth: 5.2-19.4
Inclination: -52° S
Latitude: 48° 30' N
Longitude: 81° 20' W

Data Sheet 16

Origin	Reference No.	Rock Type
Central Canada Potash, Saskatchewan	16	bituminous limestone

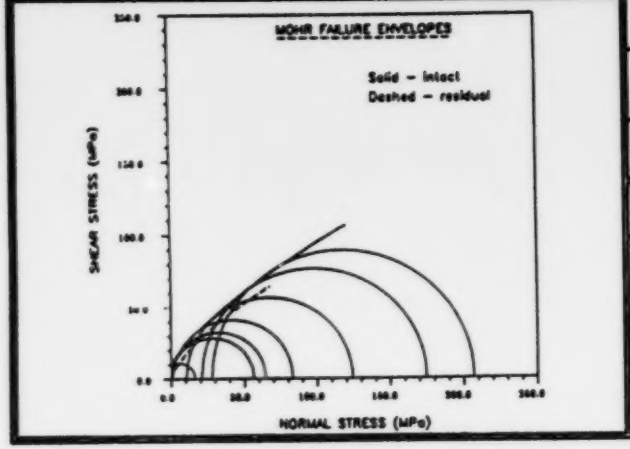
Regional Geology	Structural Characteristics
Dawson Bay Formation, middle Devonian Period	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: bituminous, calcite filled vugs, sugary	Composition
Texture: Grain Size: Colour: dark brown to black Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.46		44	89			56.37	-5.43	29.80	0.30	0.1-27.6



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
66.71	14.40	1.00	0.99	13.05	0.00	0.98

Borehole Information

Collar Elevation: 459m
Depth:
Inclination: 53° SW
Latitude: 51° 55'
Longitude: 105° 45' W

Data Sheet 17

Origin	Reference No.	Rock Type
Central Canada Potash, Saskatchewan	16	limestone, fine grained

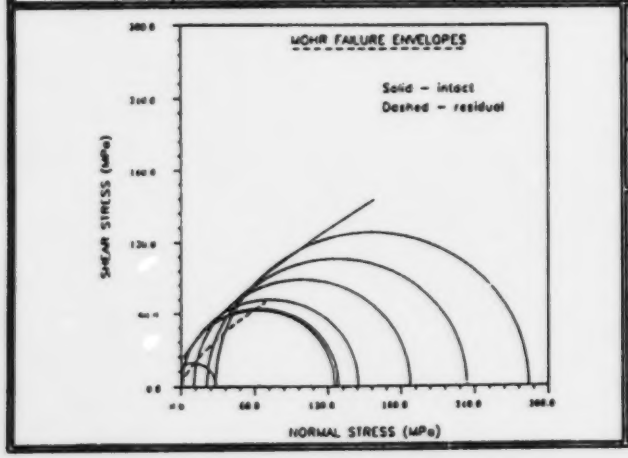
Regional Geology	Structural Characteristics
Dawson Bay Formation, middle Devonian Period	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: competent, few fractures, mottled	Composition
Texture: Grain Size: fine Colour: dark-medium grey, brownish grey Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.61		44	89			125.70	-9.40	40.08	0.26	0.1-27.6



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
127.97	12.76	1.00	0.98	7.02	0.00	0.87

Borehole Information

Collar Elevation: 459m
Depth:
Inclination: 53° SW
Latitude: 51° 55' N
Longitude: 105° 45' W

Origin	Reference No.	Rock Type
Indiana, USA	8	oolitic limestone

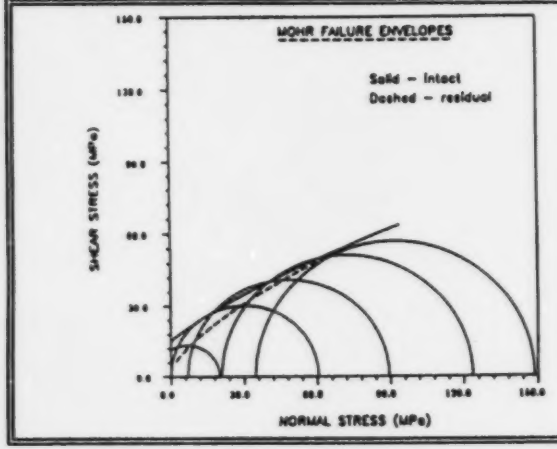
Regional Geology	Structural Characteristics
	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: faint bedding trace, orthoganal to core axis, soft	Composition
Texture: Grain Size: Colour: buff-coloured Grain Sorting: Grain Shape: Matrix:	30-50% pelecypods, gastropods, bryozoans observed in a soft, moderately cemented ooid and fossil mass

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.34	13.76	42	84	3.80		59.70	-4.76	40.80	0.25	6.9-34.5



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
60.50	4.90	1.00	0.96	6.40	0.14	0.99

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: approx 40° N
Longitude: approx 88° W

Data Sheet 19

Origin	Reference No.	Rock Type
Central Canada Potash, Saskatchewan	16	sugary limestone

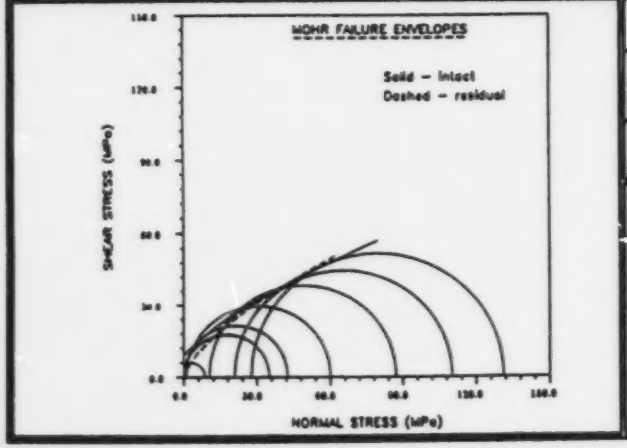
Regional Geology	Structural Characteristics
Dawson Bay Formation, middle Devonian Period	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: few fractures, some fossilization, mottled appearance, sugary	Composition
Texture: Grain Size: fine Colour: light grey Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.20		44	89			42.55	-2.91	18.03	0.28	0.1-27.6



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
43.07	7.49	1.00	0.96	9.86	0.00	1.00

Borehole Information

Collar Elevation: 459m
Depth:
Inclination: 53° SW
Latitude: 51° 55' N
Longitude: 105° 45' W

Origin	Reference No.	Rock Type
Detour Lake Mine, Ontario	5	mafic flow

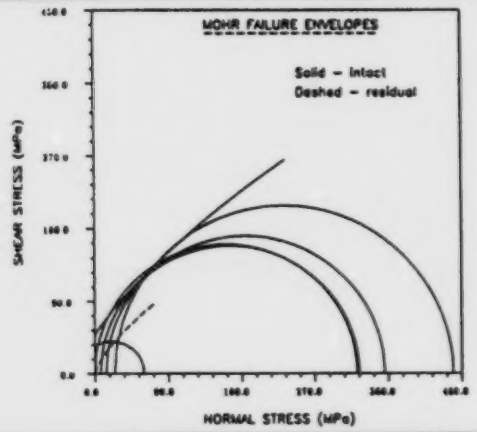
Regional Geology	Structural Characteristics
Archean rocks, of volcanic origin, Abitibi belt located on the James Bay Highlands, on the hanging wall of the excavation, basaltic flow	Dip: 35° to 40° W (orebody) Strike: avg. N 70° E Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: tight fractures, brittle	Composition
Texture: Grain Size: Colour: dark green Grain Sorting: Grain Shape: Matrix:	iron, magnesium rich, plagioclase, pyroxene, quartz

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.95	<0.1	44	89	4.65		316.91	-19.99	88.00	0.25	6.9-24.1



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
287.22	12.27	1.00	0.95	5.01	0.00	0.98

Borehole Information

Collar Elevation: 259.0m above sea level
Depth: >38m
Inclination:
Latitude: 50° 00' N
Longitude: 79° 45' W

Data Sheet 21

Origin	Reference No.	Rock Type
Detour Lake Mine, Ontario	5	mafic flow ore

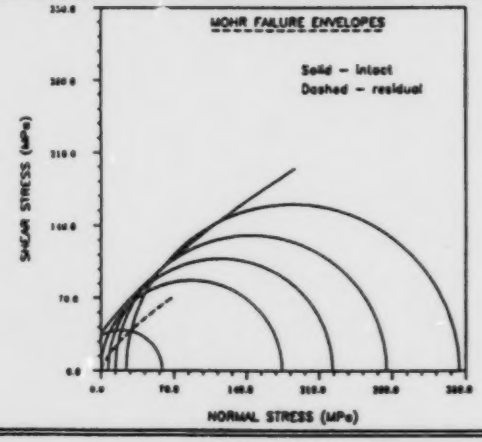
Regional Geology	Structural Characteristics
Archean rocks, of volcanic origin, located on the James Bay Highlands, on the hanging wall of the excavation, pillowed amygdaloidal basalt flow	Dip: 35° to 40° W (orebody) Strike: avg. N 70° E Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: tight fractures, brittle; sulphide-filled amygdules	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	iron, magnesium rich

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.99		44	89			173.91	-19.53	92.69	0.26	6.9-24.1



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
199.22	10.87	1.00	0.94	5.36	0.00	0.56

Borehole Information

Collar Elevation: 259.0m above sea level
Depth: >38m
Inclination:
Latitude: 50° 00' N
Longitude: 79° 45' W

Data Sheet 22

Origin	Reference No.	Rock Type
Donkin-Morien, Cape Breton	13	mudstone

Regional Geology

originates from the Carboniferous Morien Group, Sydney Basin

Structural Characteristics

Dip: 4° to 15°
Strike: NE-E
Bedding Thickness: thinly laminated medium
Fracture Spacing:
Weathering: little or none

Petrography

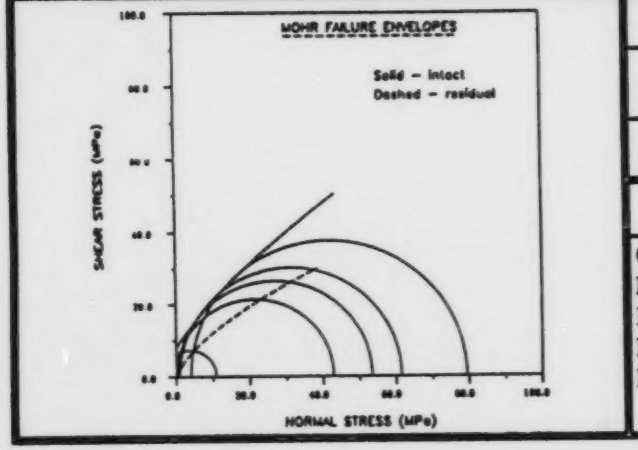
Structure: fissile, frequently containing clasts

Texture: Grain Size:
Colour: light to dark grey
Grain Sorting:
Grain Shape:
Matrix:

Composition

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.61		46	91			33.92	-3.63	1.93	0.49	0.4-5.2



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
50.84	14.39	1.00	0.95	6.65	0.00	0.55

Borehole Information

Collar Elevation: approx. -200m
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 59° 50' W

Origin	Reference No.	Rock Type
Lingan Mine, Cape Breton	7	mudstone

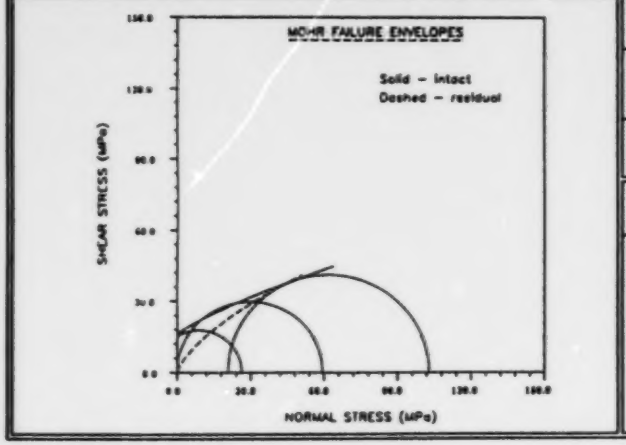
Regional Geology	Structural Characteristics
Morien Group, Glace Bay Sub-basin of the Carboniferous Sydney Basin	Dip: 4° to 15° seaward Strike: E-NE Bedding Thickness: 0.4m to 1.5m Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.70		46	91			59.40	-8.78	15.49	0.11	3.5-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
55.85	3.26	1.00	0.98	5.59	0.00	0.98

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 60° 5' W

Origin	Reference No.	Rock Type
Springhill Coal Mine, Cape Breton	14	mudstone

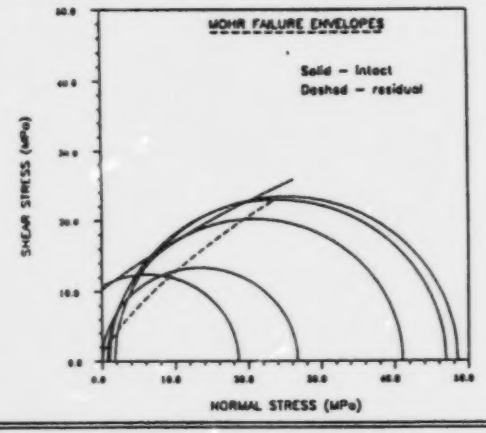
Regional Geology	Structural Characteristics
Pennsylvanian Cumberland Group, from the Cumberland Basin in the Appalachian Orogen	Dip: SW (Springhill Anticline axis) Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m³)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
		46	91			26.71	-6.21			0.4-3.5



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
39.35	4.44	1.00	0.56	9.83	0.08	0.44

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 45° 35' N
Longitude: 64° 5' W

Data Sheet 25

Origin	Reference No.	Rock Type
Central Canada Potash, Saskatchewan	16	dolomitic mudstone

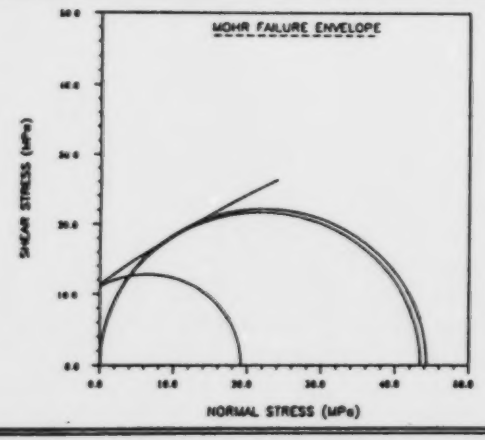
Regional Geology	Structural Characteristics
Dawson Bay Formation, middle Devonian Period	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: argillaceous. dolomitic	Composition
Texture: Grain Size: fine Colour: grey Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_s (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.50		44	89			44.31	-6.39	9.34	0.15	0.1-27.6



Hock and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
43.71	4.50	1.00	0.99			

Borehole Information

Collar Elevation: 459m
Depth:
Inclination: 53° SW
Latitude: 51° 55' N
Longitude: 105° 45' W

Origin	Reference No.	Rock Type
Lingan Mine, Cape Breton	7	sandstone

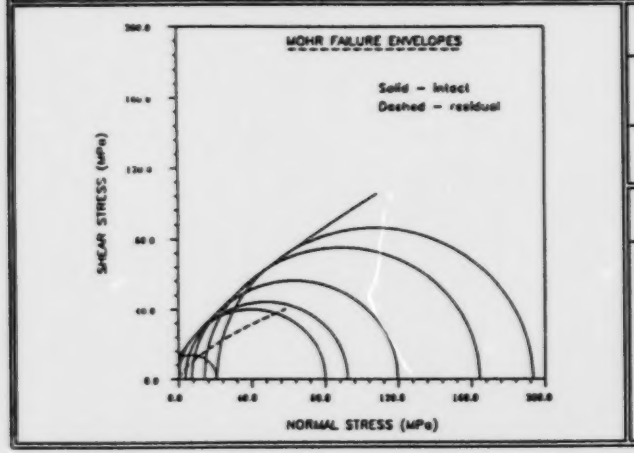
Regional Geology	Structural Characteristics
Morien Group, Glace Bay Sub-basin of the Carboniferous Sydney Basin	Dip: 4° to 15° seaward Strike: E-NE Bedding Thickness: 0.8m to 4.6m Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.66		46	91			80.02	-6.87	30.37	0.18	3.5-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
80.25	13.68	1.00	0.98	3.00	0.00	0.79

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 60° 5' W

Data Sheet 27

Origin	Reference No.	Rock Type
Central Canada Potash, Saskatchewan	16	sandstone, 2nd redbed

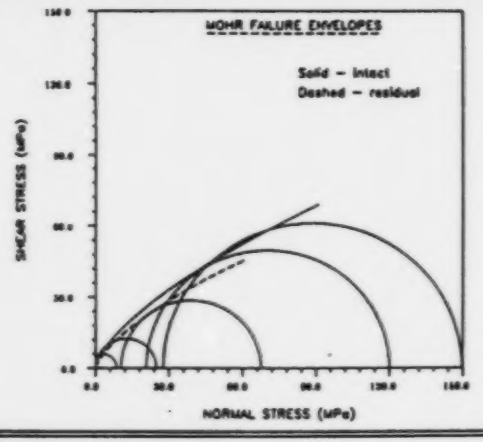
Regional Geology	Structural Characteristics
Dawson Bay Formation, middle Devonian Period	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: poorly consolidated; salt inclusions	Composition
Texture: Grain Size: Colour: reddish brown Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.53		44	89			24.90	-2.91			0.1-27.6



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
19.92	24.12	1.00	0.95	12.83	0.00	0.97

Borehole Information

Collar Elevation: 459m
Depth:
Inclination: 53° SW
Latitude: 51° 55' N
Longitude: 105° 45' W

Data Sheet 28

Origin	Reference No.	Rock Type
Donkin-Morien, Cape Breton	13	sandstone, fine grained

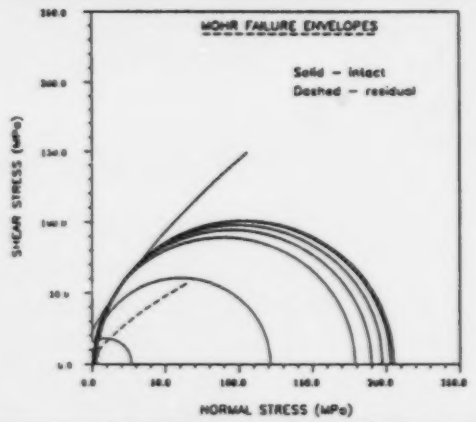
Regional Geology	Structural Characteristics
originates from the Carboniferous Morien Group, Sydney Basin	Dip: 4° to 15° Strike: NE-E Bedding Thickness: laminated to thick Fracture Spacing: none Weathering: little or none

Petrography

Structure: no fractures; massive, homogeneous, no stratification	Composition
Texture: Grain Size: 0.1-0.2mm Colour: light to dark grey Grain Sorting: Grain Shape: angular to subangular Matrix: kaolinite cement	58.5% quartz 23.3% shale 10.5% kaolinite 3.6% quartz and feldspar fragments 4.1% chert, chlorite, zircon, mica, opaques

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_s (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.46	1.36	46	91	4.43		121.25	-8.96	19.04	0.14	0.4-5.2



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
171.49	19.64	1.00	0.82	4.41	0.01	0.94

Borehole Information

Collar Elevation: -200m
Depth: 16.8m
Inclination:
Latitude: 46° 15' N
Longitude: 59° 50' W

Data Sheet 29

Origin	Reference No.	Rock Type
Prince Mine, Cape Breton	1	sandstone, fine grained

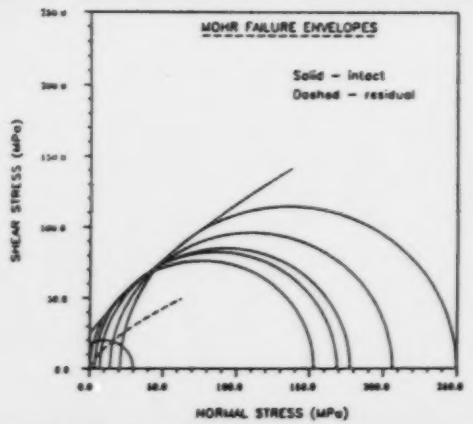
Regional Geology	Structural Characteristics
located in the Carboniferous Sydney basin, Morien Group	Dip: 4° to 15° seaward Strike: NE-E Bedding Thickness: 1.5-2.3m, mixed with siltstone Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: fine Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.63		46	91			142.87	-9.97	41.79	0.18	0.3-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
139.38	11.08	1.00	0.97	2.71	0.00	0.87

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 10' N
Longitude: 60° 5' W

Data Sheet 30

Origin	Reference No.	Rock Type
Springhill Coal Mine, Cape Breton	14	sandstone, fine grained

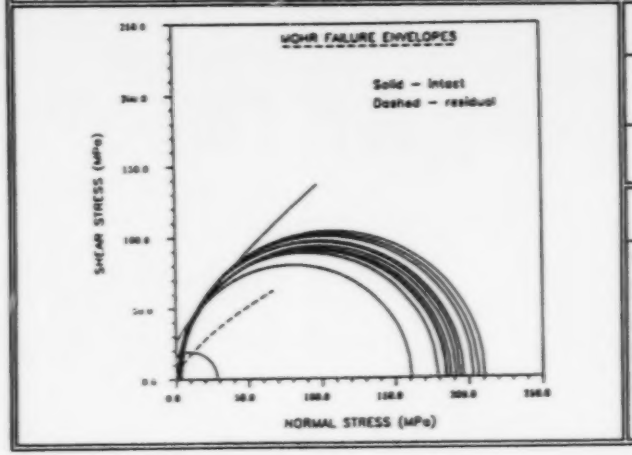
Regional Geology	Structural Characteristics
Pennsylvanian Cumberland Group, from the Cumberland Basin in the Appalachian Orogen	Dip: SW (Springhill Anticline axis) Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: fine Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
		46	91			160.76	-9.47	32.86	0.15	0.4-3.5



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
175.37	16.32	1.00	0.78	4.14	0.01	0.79

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 45° 35' N
Longitude: 64° 5' W

Origin	Reference No.	Rock Type
Niagara Falls, Ontario	15	Grimsby sandstone

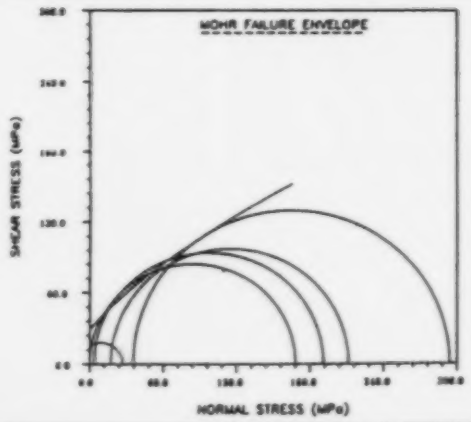
Regional Geology	Structural Characteristics
lower Silurian, Medina Group, Grimsby Formation	Dip: Strike: Bedding Thickness: 12.3m Fracture Spacing: Weathering:

Petrography

Structure: quartzose, mottled	Composition
Texture: Grain Size: Colour: red Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.53	6.60	44	98	3.30		168.20	-8.98	24.88	0.36	3.5-35.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
147.83	8.78	1.00	0.89			

Borehole Information

Collar Elevation:
Depth: 143.7-235.3m
Inclination:
Latitude: 43° 10' N
Longitude: 79° 35' W

Origin	Reference No.	Rock Type
Campbell's Quarry, Ontario	21	sandstone, medium grained

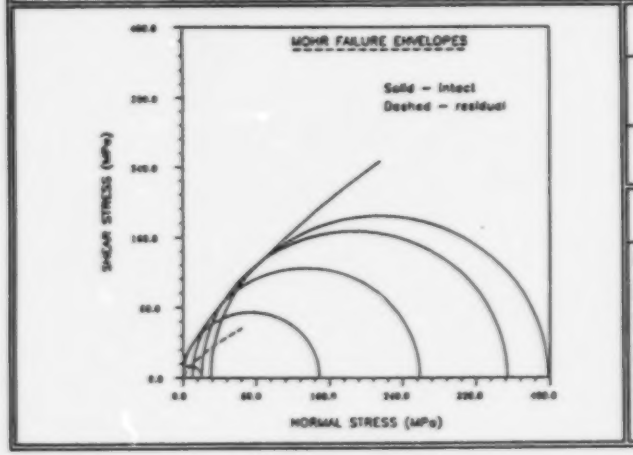
Regional Geology	Structural Characteristics
Nepean Formation, Chazy period, Upper Cambrian age	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering: advanced

Petrography

Structure: mature quartz arenite, with some quartzite bands	Composition
Texture: Grain Size: 0.14mm (medium grained) Colour: beige-orangy Grain Sorting: well sorted Grain Shape: well rounded Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_o (MPa)	σ_1 (MPa)	E (GPa)	v	σ_3 (MPa)
2.40	8.15	44	111	4.09		145.78	-6.82	39.24	0.50	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
159.93	23.98	1.00	0.99	3.62	0.00	0.85

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 45° 20' N
Longitude: 75° 40' W

Data Sheet 33

Origin	Reference No.	Rock Type
Donkin-Morien, Cape Breton	13	sandstone, medium grained

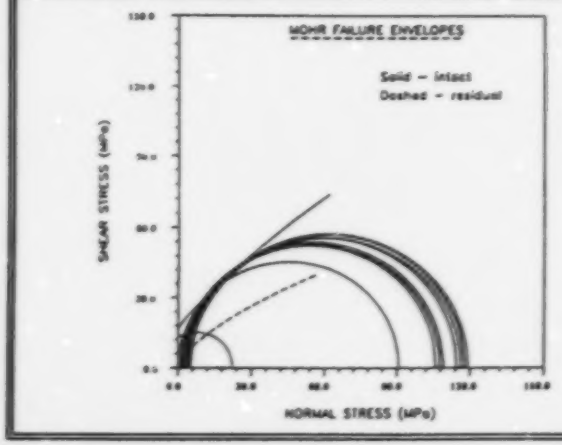
Regional Geology	Structural Characteristics
originates from the Carboniferous Morien Group, Sydney basin	Dip: 4° to 15° Strike: NE-E Bedding Thickness: laminated to thick Fracture Spacing: Weathering: little or none

Petrography

Structure: some fracturing, clastic grains and lithic fragments	Composition
Texture: Grain Size: 0.15-0.30mm Colour: light grey to medium grey Grain Sorting: Grain Shape: Matrix: knolinite	60.8% quartz grains and fragments 20.2% shale 3.5% quartz-feldspar fragments 2.6% chert 4.9% mica, chlorite, sphene, etc.

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_s (MPa)	σ_1 (MPa)	E (GPa)	v	σ_3 (MPa)
2.42		46	91			88.23	-7.46	20.38	0.21	0.4-5.2



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
94.00	10.64	1.00	0.95	2.79	0.01	0.75

Borehole Information

Collar Elevation: approx. -200m
Depth: 5.2m
Inclination:
Latitude: 46° 15' N
Longitude:59° 50' W

Data Sheet 34

Origin	Reference No.	Rock Type
Prince Mine, Cape Breton	1	sandstone, medium grained

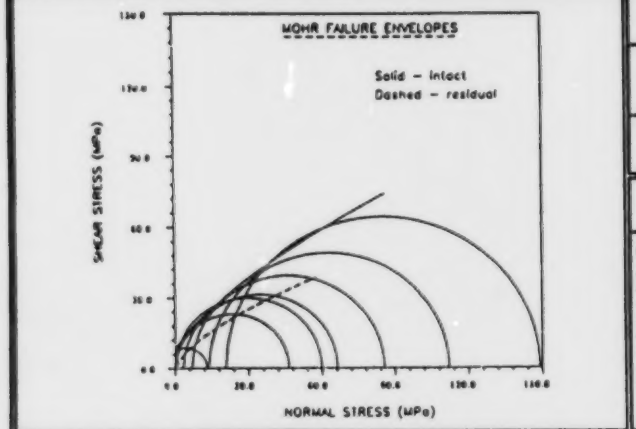
Regional Geology	Structural Characteristics
located in the Carboniferous Sydney basin, Morien Group	Dip: 4° to 15° seaward Strike: NE-E Bedding Thickness: 1.5-2.3m, mixed with siltstone Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Meduim Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.31		46	91			56.25	-4.35	15.41	0.18	0.3-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
49.42	12.49	1.00	0.97	3.87	0.00	0.87

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 10' N
Longitude: 60° 5' W

Data Sheet 35

Origin	Reference No.	Rock Type
Springhill Coal Mine, Cape Breton	14	sandstone, medium grained

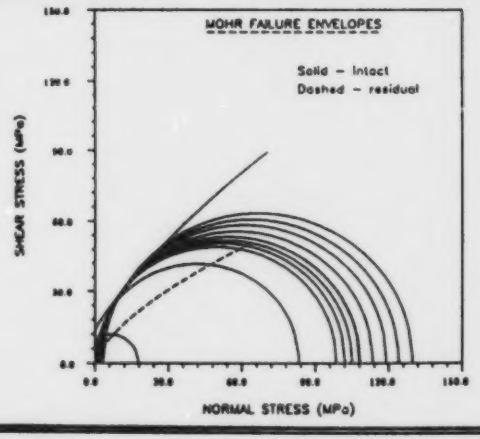
Regional Geology	Structural Characteristics
Pennsylvanian Cumberland Group, from the Cumberland Basin the Appalachian Orogen	Dip: SW (Springhill Anticline axis) Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: medium Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
		46	91			83.30	-5.91	24.00	0.20	0.4-3.5



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
93.94	16.72	1.00	0.94	4.70	0.01	0.80

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 45° 35' N
Longitude: 64° 5' W

Origin	Reference No.	Rock Type
Niagara Falls, Ontario	15	whirlpool sandstone

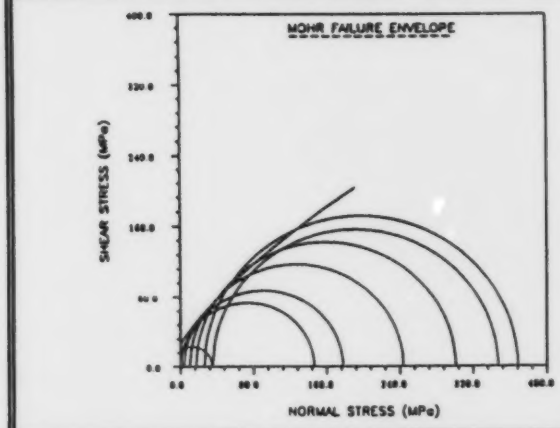
Regional Geology	Structural Characteristics
lower Silurian, Cataract Group, Whirlpool Formation	Dip: Strike: Bedding Thickness: 4.6m Fracture Spacing: Weathering:

Petrography

Structure: orthoquartzic	Composition
Texture: Grain Size: fine Colour: white and grey Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.50		44	98			146.42	-11.61			3.5-35.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
170.15	14.84	1.00	0.90			

Borehole Information

Collar Elevation:
Depth: 183.8-256.3m
Inclination:
Latitude: 43° 10' N
Longitude: 79° 35' W

Data Sheet 37

Origin	Reference No.	Rock Type
Prince Mine, Cape Breton	1	shale

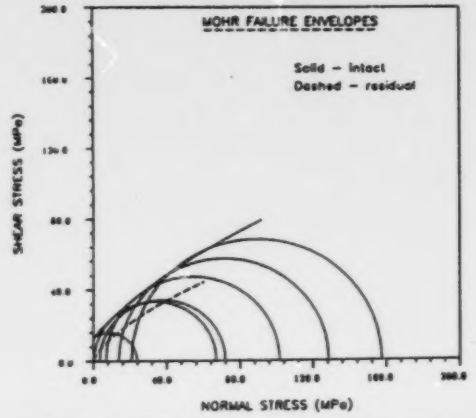
Regional Geology	Structural Characteristics
located in the Carboniferous Sydney basin, Morien Group	Dip: 4° to 15° seaward Strike: NE-E Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.60		46	91			89.30	-7.96	17.40	0.18	0.3-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
69.53	9.39	1.00	0.96	3.37	0.00	0.99

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 10' N
Longitude: 60° 5' W

Data Sheet 38

Origin	Reference No.	Rock Type
Donkin-Morien, Cape Breton	13	siltstone

Regional Geology

originates from the Carbiniferous Morien Group, Sydney Basin

Structural Characteristics

Dip: 4° to 15°
Strike: NE-E
Bedding Thickness: laminated to thin
Fracture Spacing:
Weathering: fresh to slightly weathered

Petrography

Structure: argillaceous partings, closely spaced, sandy

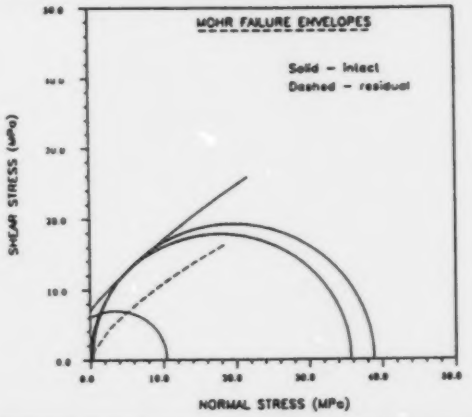
Texture:
Grain Size: 0.04-0.1mm
Colour: dark greenish grey
Grain Sorting:
Grain Shape: subangular
Matrix:

Composition

35.0% siderite, 33.6% clays (illite, smectite), 20.0% quartz, 6.4% calcite, 2.8% mica, 2.1% chlorite and opaques

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.86		46	91			35.68	-3.48	22.38	0.20	0.4-5.2



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
36.36	8.95	1.00	1.00	4.41	0.01	0.94

Borehole Information

Collar Elevation: approx. -200m
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 59° 50' W

Origin	Reference No.	Rock Type
Lingan Mine, Cape Breton	7	siltstone

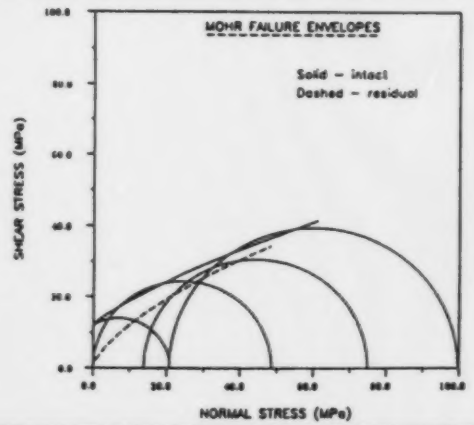
Regional Geology	Structural Characteristics
Morien Group, Glace Bay Sub-basin of the Carboniferous Sydney basin	Dip: 4° to 15° seaward Strike: E-NE Bedding Thickness: 1.1m to 3.0m Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.70		46	91			48.64	-6.97	36.58	0.21	3.5-20.7



Hock and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
45.35	3.92	1.00	0.94	4.43	0.03	0.86

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 15' N
Longitude: 60° 5' W

Data Sheet 40

Origin	Reference No.	Rock Type
Prince Mine, Cape Breton	1	siltstone

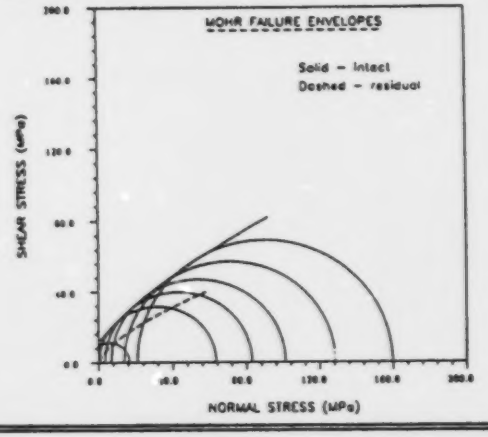
Regional Geology	Structural Characteristics
located in the Carboniferous Sydney basin, Morien Group	Dip: 4° to 15° seaward Strike: NE-E Bedding Thickness: 1.5-2.3m, mixed with sandstone Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: grey Grain Sorting: Grain Shape: Matrix:	90% quartz, 10% opaque minerals, phlogopite and obsidian, several 0.5mm thick coal bands

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.48		46	91			82.08	-5.59	14.16	0.17	0.3-20.7



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
63.26	11.24	1.00	1.00	2.86	0.00	0.95

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 10' N
Longitude: 60° 5' W

Data Sheet 41

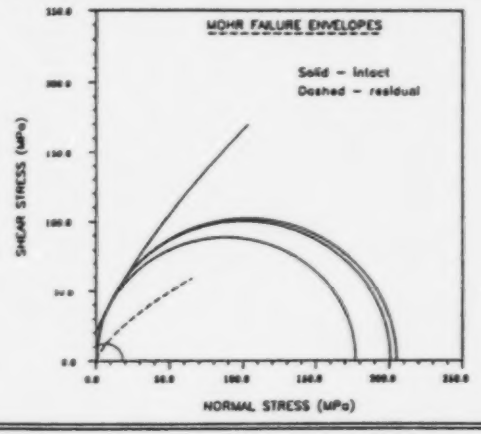
Origin	Reference No.	Rock Type
Springhill Coal Mine, Cape Breton	14	siltstone

Regional Geology	Structural Characteristics
Pennsylvanian Cumberland Group, from the Cumberland Basin in the Appalachian Orogen	Dip: SW (Springhill Anticline axis) Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography	
Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
		46	91			177.20	-6.14	30.00	0.14	0.4-3.5



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
189.38	30.61	1.00	0.97	3.34	0.00	1.00

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 45° 35' N
Longitude: 64° 5' W

Origin	Reference No.	Rock Type
Copper Cliff South Mine, Ontario	12	sulphide ore

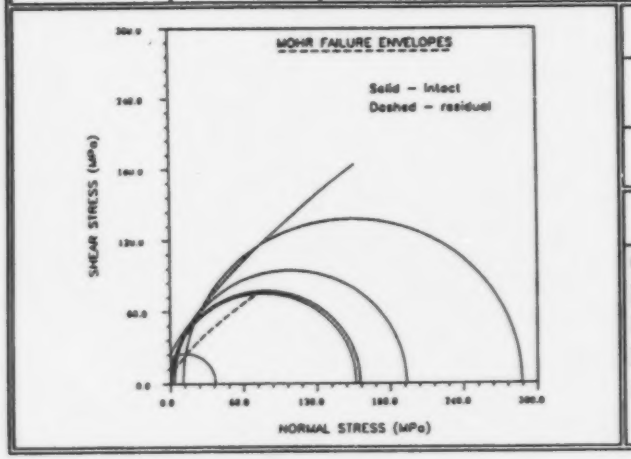
Regional Geology	Structural Characteristics
southern rim of the Sudbury Irruptive, in the Middle Precambrian McKim pelites, Southern Province sulphide bearing crystal tuff unit	Dip: 65° W Strike: NS Bedding Thickness: up to 15m Fracture Spacing: 36cm Weathering:

Petrography

Structure: crystalline	Composition
Texture: Grain Size: very fine grained Colour: metallic yellow-bronze, grey Grain Sorting: Grain Shape: Matrix:	pyrite chalcopyrite pyrrhotite quartz 4% nickel 2% copper

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_1 (MPa)	E (GPa)	v	σ_3 (MPa)
2.99	<0.1	42-292	84-584	4.03		155.10	-12.32	77.20	0.26	1.0-10.3



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
175.66	17.49	1.00	0.84	6.43	0.06	0.92

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 46° 25' N
Longitude: 81° 10' W

Data Sheet 43

Origin	Reference No.	Rock Type
Hislop Township, Ontario	3	syenite

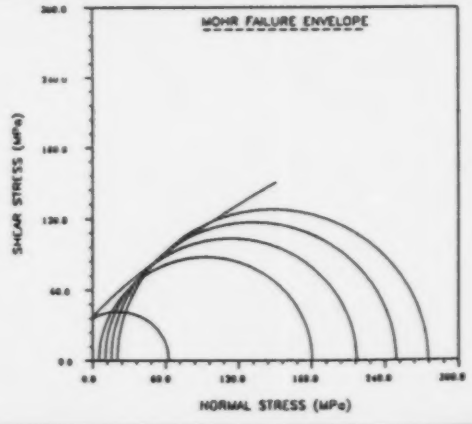
Regional Geology	Structural Characteristics
Archean, part of the Abitibi Greenstone Belt, from a chloritic, silicified dike and stock that have been mixed with breccia	Dip: 75° to 80° NE Strike: NW-SE generally Bedding Thickness: dike-7.6-39.6m, stock-48.8m Fracture Spacing: 0.3-1.0m Weathering:

Petrography

Structure: rough, irregular joints	Composition
Texture: Grain Size: medium to coarse Colour: pink-purple-grey Grain Sorting: Grain Shape: Matrix:	albite with some sericite alteration sulphides (pyrite), hematite little or no quartz or ferromagnesians

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.66	0.14	46	91	5.80		253.62	-20.87	76.49	0.36	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
179.25	7.65	1.00	0.94			

Borehole Information

Collar Elevation:
Depth: 24.4m
Inclination:
Latitude: 48° 30' N
Longitude: 80° 15' W

Origin	Reference No.	Rock Type
Detour Lake Mine, Ontario	5	talc-chlorite

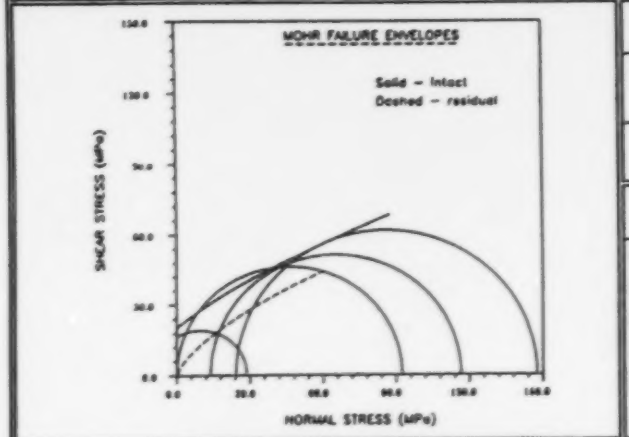
Regional Geology	Structural Characteristics
altered Archean rocks of volcanic origin located on the James Bay Highlands, on the foot wall of the excavation	Dip: 35° to 40° W (orebody) Strike: avg. N 70° E Bedding Thickness: Fracture Spacing: Weathering: fresh

Petrography

Structure: massive, irregularly foliated, finely banded	Composition
Texture: Grain Size: fine Colour: dark green, light greyish green Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.97		44	89			92.43	-9.58	50.82	0.34	6.9-24.1



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
79.56	4.65	1.00	0.92	3.22	0.00	0.85

Borehole Information

Collar Elevation: 259.0m above s.l.
Depth: >38m
Inclination:
Latitude: 50° 00' N
Longitude: 79° 45' W

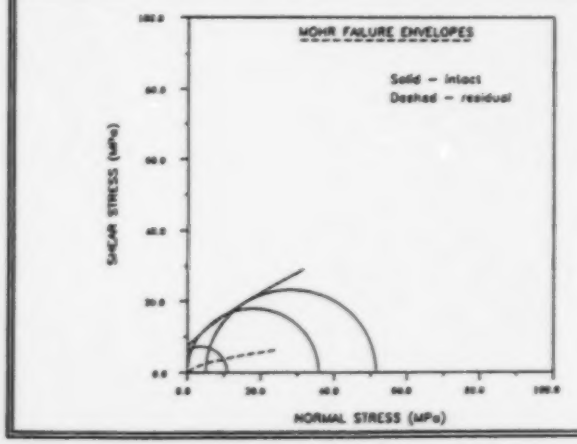
Origin	Reference No.	Rock Type
Hislop Township, Ontario	3	talc-chlorite-schist

Regional Geology	Structural Characteristics
Archean, part of the Abitibi Greenstone Belt altered ultramafic flow; intermittent clay, and pyrite is disseminated throughout	Dip: 75° to 80° NE Strike: NW-SE generally Bedding Thickness: 91.4m Fracture Spacing: Weathering:

Petrography	
Structure: closely spaced joints; no visible foliation, soft	Composition
Texture: Grain Size: Colour: bluish black Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.84		46	91			35.79	-3.61	35.82	0.29	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
33.37	6.70	1.00	0.98	0.24	0.00	0.99

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 30' N
Longitude: 80° 15' W

Data Sheet 46

Origin	Reference No.	Rock Type
Eldrich Mine, Quebec	10	tonalite

Regional Geology

southern volcanic zone of the Abitibi greenstone belt, altered rocks from the NW sector of the Flavarian batholith, Blake River Group, Archean age, result of the complete mixing of mafic and felsic magmas

Structural Characteristics

Dip: 30° to 45°
Strike: 30° SE
Bedding Thickness:
Fracture Spacing:
Weathering:

Petrography

Structure: frequent fractures, heterogenous composition, fine to grainy

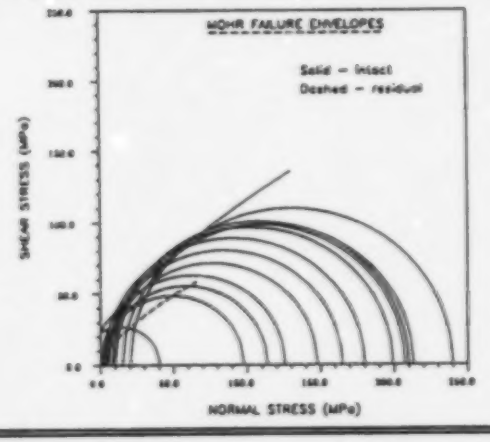
Texture: Grain Size:
Colour: pinkish
Grain Sorting:
Grain Shape:
Matrix:

Composition

50-60% oligoclase, 15-30% quartz, hornblende, accessory minerals: pistachite, chlorite, amphibole, sericite, opaque minerals

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.74	0.14	46	91	6.27		123.42	-13.54	73.58	0.23	1.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
138.72	10.92	1.00	0.74	4.42	0.04	0.36

Borehole Information

Collar Elevation:
Depth:
Inclination:
Latitude: 48° 19' N
Longitude: 79° 11' W

Data Sheet 47

Origin	Reference No.	Rock Type
Bousquet Mine, Quebec	18	tuff

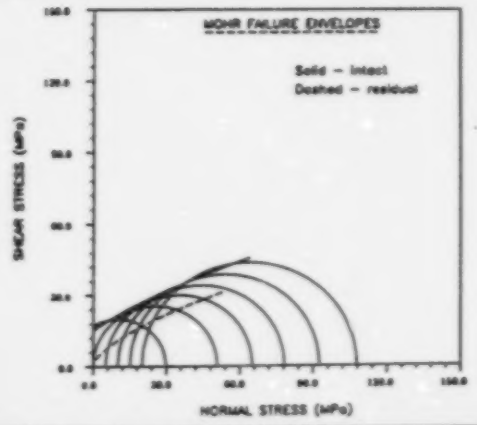
Regional Geology	Structural Characteristics
Upper Blake River Group, in Abitibi Greenstone Belt, Superior Province (Archean Age) viens of quartz, garnets in some areas schistose appearance, sericite conc. along schist planes	Dip: 85° Strike: 100° Bedding Thickness: 18.3m-36.6m Fracture Spacing: 5-30cm Weathering: some

Petrography

Structure: tightly banded; joints vertical, smooth planar to slickenside planar	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	siliceous, contains pyrite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_1 (MPa)	E (GPa)	ν	σ_3 (MPa)
2.92		46	91			50.83	-9.95	58.79	0.29	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
54.78	3.72	1.00	0.95	2.72	0.04	0.17

Borehole Information

Collar Elevation:
Depth: 18.3m
Inclination: -72° N
Latitude: 48° 15' N
Longitude: 78° 28' W

Data Sheet 48

Origin	Reference No.	Rock Type
Chimo Mine, Quebec	19	tuff

Regional Geology

upper Malartic Group, in the Abitibi Greenstone Belt of the Superior province (Archean Age), W-NW belt of metasediments with contact metavolcanics at North, chloritized amphiboles and calcified alterations observed

Structural Characteristics

Dip: 70° to 80°
Strike: 135°
Bedding Thickness: 12.2m
Fracture Spacing: 5-30cm
Weathering: little to none

Petrography

Structure: tight, cross-jointed joints, smooth, planar joints

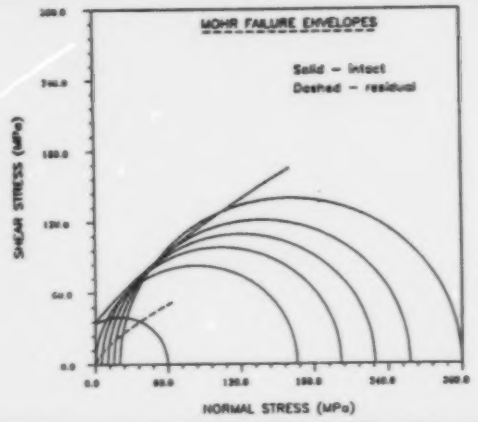
Texture:
Grain Size: fine to medium
Colour: white to light grey
Grain Sorting:
Grain Shape:
Matrix:

Composition

siliceous

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.86		46	91			165.92	-19.91	95.49	0.23	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
185.43	9.23	1.00	0.93	2.63	0.00	0.62

Borehole Information

Collar Elevation:
Depth: 24.7m
Inclination: -90°
Latitude: 48° 2' N
Longitude: 77° 10' W

Data Sheet 49

Origin	Reference No.	Rock Type
Kidd Creek Mine, Ont	22	andesite (foliated)

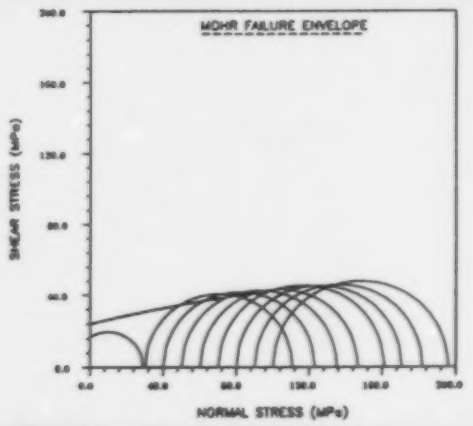
Regional Geology	Structural Characteristics
Abitibi orogenic belt N-W facing felsic tuffs and breccia	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: structural foliation	Composition
Texture: Grain Size: fine Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.82		47	110		6.30		-9.73			30.0-100.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
59.88	1.04	1.00	0.87			

Borehole Information

Collar Elevation: 1956m
Depth: 273-275m
Inclination: 0°
Latitude: 48° 41' 30" N
Longitude: 81° 22' W

Data Sheet 50

Origin	Reference No.	Rock Type
Kidd Creek Mine, Ont	22	andesite

Regional Geology

Abitibi orogenic belt
N-W facing felsic tuffs and breccia

Structural Characteristics

Dip:
Strike:
Bedding Thickness:
Fracture Spacing:
Weathering:

Petrography

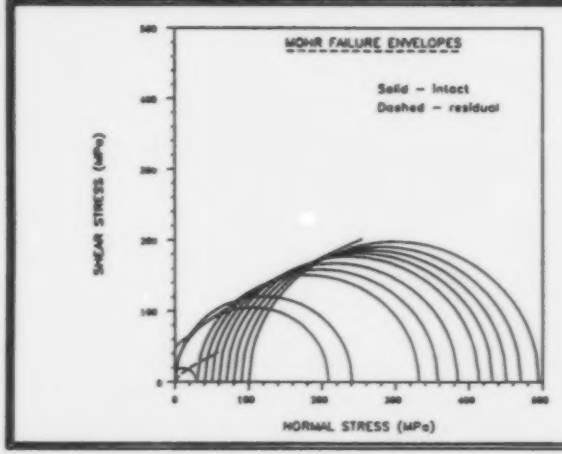
Structure:

Texture: Grain Size: medium
Colour: dark gray
Grain Sorting:
Grain Shape:
Matrix:

Composition

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
3.05		47	110	6.40		209.50	-9.73	95.76	0.26	30.0-100.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
208.96	5.83	1.00	0.93	1.16	0.00	0.46

Borehole Information

Collar Elevation: 1956m
Depth: 486-793m
Inclination: 0°
Latitude: 48° 41' 30" N
Longitude: 81° 22' W

Data Sheet 51

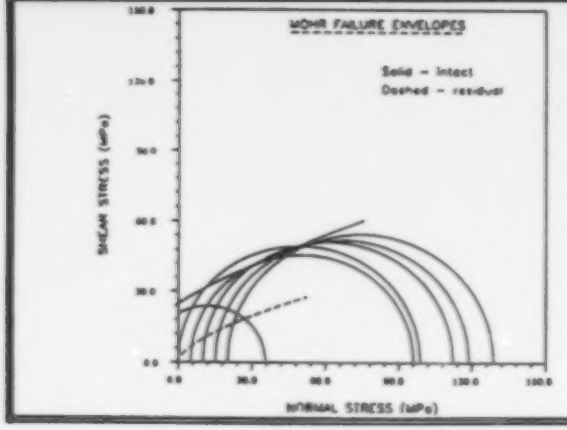
Origin	Reference No.	Rock Type
Béliveau Mine, P.Q.	24	basalt

Regional Geology	Structural Characteristics
E-W trending Archean volcanics and pyroclastics of the lower Malartic subgroup	Dip: 85° S Strike: 90° E Bedding Thickness: >200m Fracture Spacing: ±1m Weathering: intense

Petrography	
Structure: intense alterations	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	chlorite, quartz, white mica, carbonate, albite

Mechanical Properties

γ_d (Mg/m³)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.85		47	110			98.87	-11.83	62.93	0.38	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
84.87	3.26	1.00	0.82	1.02	0.008	0.67

Borehole Information

Collar Elevation: -49m (1st level)
Depth: 9.5m
Inclination: horizontal
Latitude: 48° 08' 24" N
Longitude: 77° 31' W

Origin	Reference No.	Rock Type
Strathcona Mine, Ont	26	breccia (late granite)

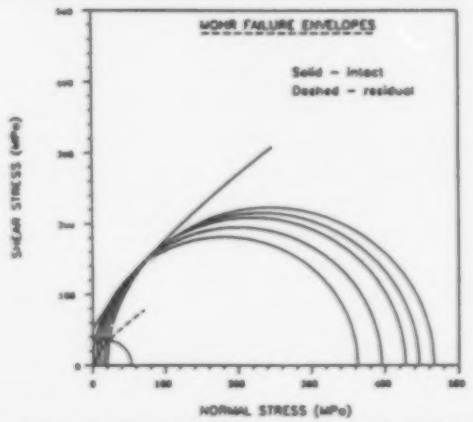
Regional Geology	Structural Characteristics
North rim of the Sudbury Basin between gneiss complex and irruputive, retrogressive metamorphism is widespread	Dip: Strike: Bedding Thickness: 9-60m Fracture Spacing: Weathering:

Petrography

Structure: rock fragments in fine grained matrix	Composition
Texture: Grain Size: fragments 20mm. to 3000mm. Colour: light gray Grain Sorting: gap sorted Grain Shape: subangular Matrix: fine grained, light colored	pyrrhitite, pentlandite, chalcopyrite, sulphides, silicates

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_s (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.71		45	110			362.97	-17.77	84.31	0.27	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
337.00	15.39	1.00	0.95	3.26	0.00	0.86

Borehole Information

Collar Elevation:
Depth: 783m
Inclination:
Latitude: 9900 N (mine co-ordinate)
Longitude: 22200 E (mine co-ordinate)

Data Sheet 53

Origin	Reference No.	Rock Type
Béliveau Mine, P.Q.	24	diorite

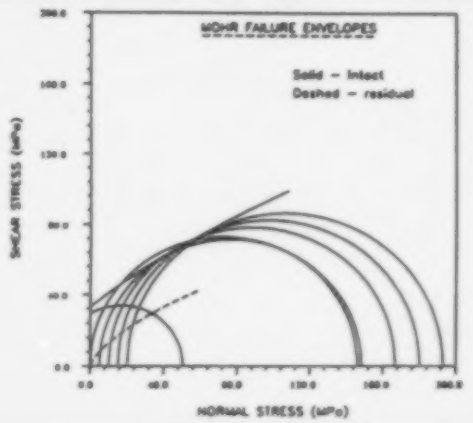
Regional Geology	Structural Characteristics
S-E of the Abitibi orogenic belt within the Malartic group Part of the Val d'Or + Dubuisson formations Contact with batholith of Bourlamaque on west side	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: mineralized dyke	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	albite 15 to 60%, quartz 10 to 50%, chlorite 5 to 40%, carbonate 5 to 25%, sericite 0 to 25%

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.80		47	110			146.11	-16.87	70.26	0.34	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
132.95	5.05	1.00	0.95	1.89	0.00	0.53

Borehole Information

Collar Elevation: -50m (1st level)
Depth: 13.5m
Inclination: vertical
Latitude: 48° 08' 24" N
Longitude: 77° 31' W

Data Sheet 54

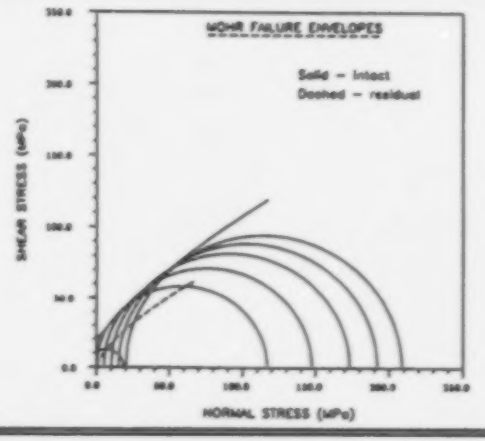
Origin	Reference No.	Rock Type
Gays River Mine, N.S.	25	dolomite (micrite)

Regional Geology	Structural Characteristics
Carboniferous (Visean sub-system) Dolomitized carbonate reef structure	Dip: 45° Strike: E-W Bedding Thickness: well developed, irregular Fracture Spacing: Weathering:

Petrography	
Structure: algal, skeletal, coral bearing, micritic	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	carbonate

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.73		45	100			116.91	-6.42	55.42	0.45	1.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
108.97	11.94	1.00	0.97	5.70	0.00	0.98

Borehole Information

Collar Elevation:
Depth: 30m
Inclination: horizontal, due north
Latitude: 45° 00' N
Longitude: 63° 00' W

Data Sheet 55

Origin	Reference No.	Rock Type
Strathcona Mine, Ont	26	gneiss (mafic)

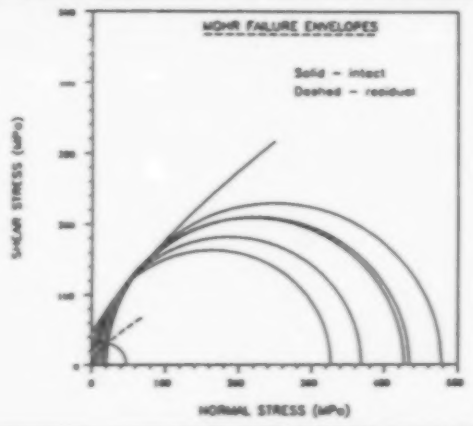
Regional Geology	Structural Characteristics
North rim of the Sudbury Basin 'Granite' Gneiss complex derived as the result of regional metamorphism and metasomatism	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure: irregular gneissosity, curved, folded	Composition
Texture: Grain Size: medium Colour: light gray Grain Sorting: Grain Shape: Matrix:	Streaks of pyroxene and amphibole banded with andesine and quartz

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.93		45	110			326.75	-15.85	95.00	0.28	5.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
318.18	17.92	1.00	0.98	2.51	0.00	0.60

Borehole Information

Collar Elevation:
Depth: 747m
Inclination:
Latitude: 11500 N (mine co-ordinate)
Longitude: 21700 E (mine co-ordinate)

Data Sheet 56

Origin	Reference No.	Rock Type
Gays River Mine, N.S.	25	greywacke (massive)

Regional Geology

Ordovican
Goldenville Formation
Basement Unit

Structural Characteristics

Dip: 45°
Strike: E-W
Bedding Thickness: thick, folded
Fracture Spacing: highly jointed
Weathering:

Petrography

Structure: massive

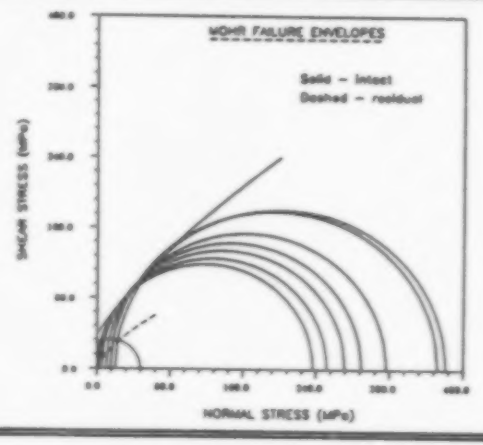
Texture: Grain Size:
Colour:
Grain Sorting:
Grain Shape:
Matrix:

Composition

quartzite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.69		45	100			236.72	-15.93	60.81	0.26	2.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
244.28	15.25	1.00	0.98	2.81	0.00	0.86

Borehole Information

Collar Elevation:
Depth: 17m
Inclination: horizontal, due north
Latitude: 45° 00'
Longitude: 63° 00'

Data Sheet 57

Origin	Reference No.	Rock Type
Lupin Mine, N.W.T.	23	phyllite

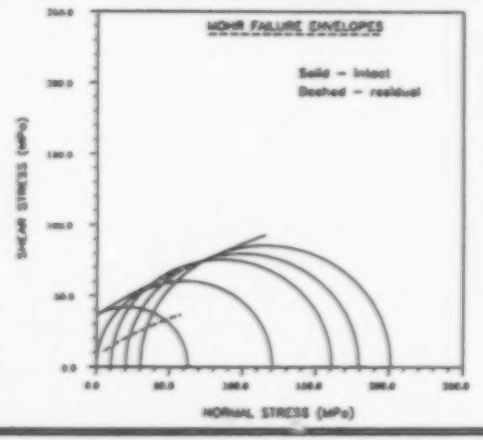
Regional Geology	Structural Characteristics
Contwoyto Formation turbidites of the Archean Yellowknife Supergroup metamorphic-lower amphibolite facies	Dip: -80° Strike: 030° Bedding Thickness: 5-30m Fracture Spacing: 1m Weathering: none

Petrography

Structure: schistose	Composition
Texture: Grain Size: fine Colour: grey Grain Sorting: Grain Shape: Matrix:	quartz, chlorite, muscouite, biotite, garnet, cordierite, graphite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_1 (MPa)	E (GPa)	v	σ_3 (MPa)
2.87		35	85	4.98		120.60	-20.89	52.30	0.21	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
127.55	3.57	1.00	0.98	1.39	0.05	0.30

Borehole Information

Collar Elevation: 1365m
Depth: 11.0m
Inclination: 06°
Latitude: 10180 N
Longitude: 1045 E

Data Sheet 58

Origin	Reference No.	Rock Type
Lupin Mine, N.W.T.	23	quartzite (metagreywacke)

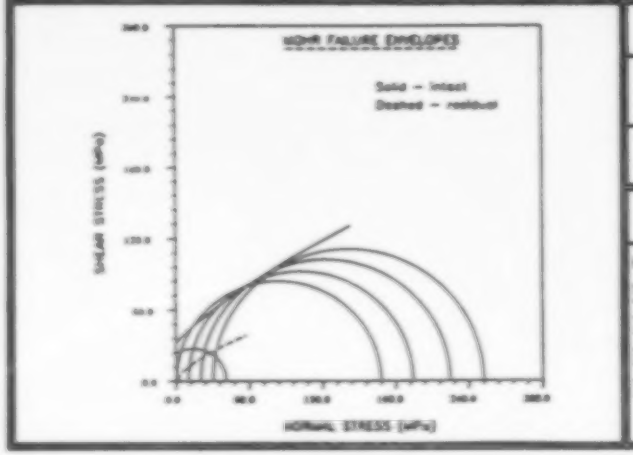
Regional Geology	Structural Characteristics
Contwoyto Formation turbidites of the Archean Yellowknife Supergroup metamorphic-lower amphibolite facies	Dip: -80° Strike: 030° Bedding Thickness: 5-30m Fracture Spacing: 1.5m Weathering: none

Petrography

Structure: homogeneous interbeaded	Composition
Texture: Grain Size: coarse Colour: grey Grain Sorting: homogenous Grain Shape: subangular Matrix: quartz	quartz, feldspar, biotite, sericite

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.70		35	85	3.54		168.06	-13.68	49.19	0.42	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
148.16	6.81	1.00	0.94	1.29	0.00	0.60

Borehole Information

Collar Elevation: 1365m
Depth: 82m
Inclination: 0°
Latitude: 10170 N
Longitude: 10120 E

Data Sheet 59

Origin	Reference No.	Rock Type
Kidd Creek Mine, Ont	22	rhyolite

Regional Geology

Abitibi orogenic belt
N-W facing felsic tuffs and breccia

Structural Characteristics

Dip:
Strike:
Bedding Thickness:
Fracture Spacing:
Weathering:

Petrography

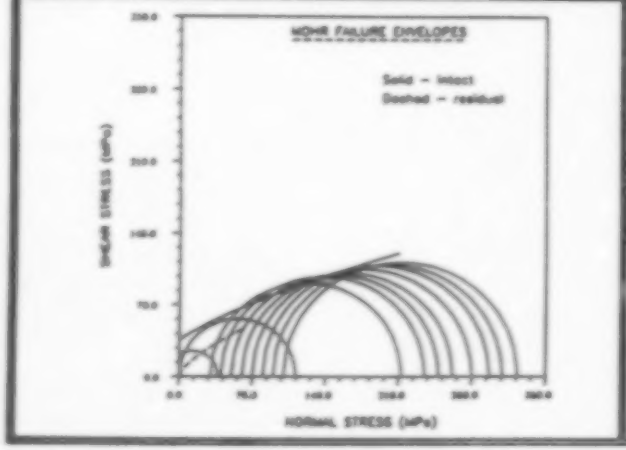
Structure: fragmented

Texture: Grain Size:
Colour:
Grain Sorting:
Grain Shape:
Matrix:

Composition

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.75		36	90	6.16		111.98	-12.48	80.75	0.39	10.0-100.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
122.77	3.29	1.00	0.90	2.98	0.00	0.85

Borehole Information

Collar Elevation: 2045m
Depth: 403-408m
Inclination: 0°
Latitude: 48° 41' 30" N
Longitude: 81° 22' W

Origin	Reference No.	Rock Type
Lupin Mine, N.W.T.	23	sulphide iron

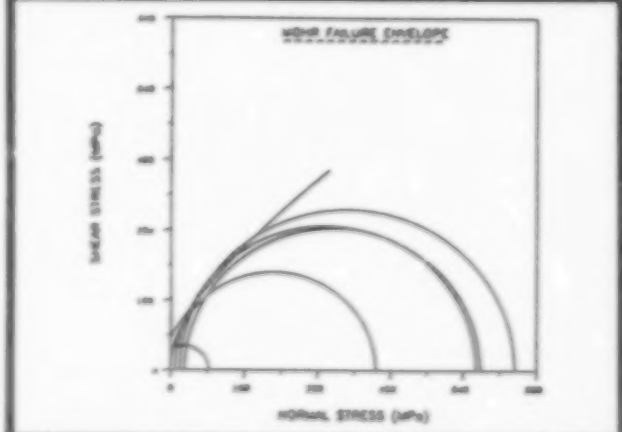
Regional Geology	Structural Characteristics
Contwoyto Formation turbidites of the Archean Yellowknife Supergroup, Metamorphic - lower amphibolite facies	Dip: -80° Strike: 010° Bedding Thickness: 8m Fracture Spacing: 0.4m Weathering: none

Petrography

Structure: interbanded	Composition
Texture: Grain Size: coarse, 0.4mm Colour: dark green, brown Grain Sorting: Grain Shape: subangular Matrix:	quartz, hornblende, pyrrhotite, arsenopyrite, grunerite, chlorite, chert

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
3.21		35	90	6.62		447.73	-27.90	101.10	0.24	10.0-30.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
515.26	16.78	1.00	0.82			

Borehole Information

Collar Elevation: 1365m
Depth: 2m
Inclination: 0°
Latitude: 10° 16' 5" N
Longitude: 10° 11' 8" E

Data Sheet 61

Origin	Reference No.	Rock Type
Kidd Creek Mine, Ont	22	sulphide zinc

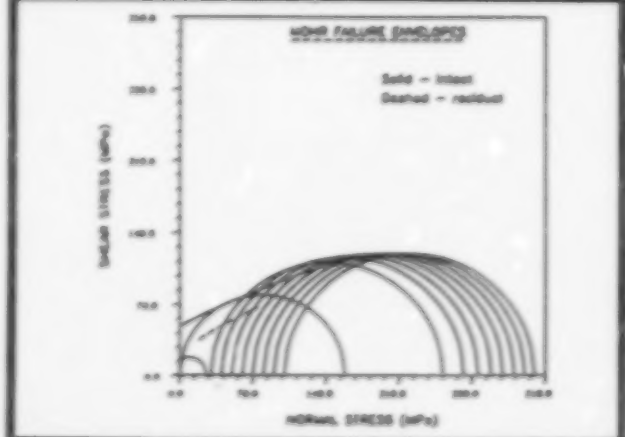
Regional Geology	Structural Characteristics
Abitibi orogenic belt N-W facing felsic tuffs and breccia	Dip: 75° N Strike: N 20° E Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	massive chalcopyrite and sphalerite, breccia ore of chalcopyrite replacing rhyolite breccia

Mechanical Properties

γ_d (Mg/m³)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
3.72		36	70	5.81		158.54	-8.86	82.16	0.16	10.0-100.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
157.47	2.80	1.00	0.71	2.88	0.30	0.75

Borehole Information

Collar Elevation: 2045m
Depth: 423m
Inclination: 0°
Latitude: 48° 41' 30" N
Longitude: 81° 22' W

Data Sheet 62

Origin	Reference No.	Rock Type
Kidd Creek Mine, Ont	22	talc - carbonate

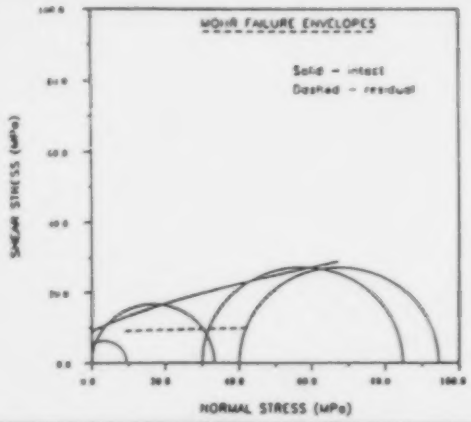
Regional Geology	Structural Characteristics
Abitibi orogenic belt N-W facing felsic tuffs and breccia	Dip: Strike: Bedding Thickness: Fracture Spacing: Weathering:

Petrography

Structure:	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	

Mechanical Properties

γ_d (Mg/m³)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_u (MPa)	σ_t (MPa)	E (GPa)	v	σ_3 (MPa)
2.84		47	110	4.85		33.34	-3.17	28.55	0.58	10.0-100.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
27.64	2.27	1.00	0.92	0.06	0.30	

Borehole Information

Collar Elevation: 1956m
Depth: 979-983m
Inclination: 0°
Latitude: 48° 41' 30" N
Longitude: 81° 22' W

Data Sheet 63

Origin	Reference No.	Rock Type
Béliveau Mine, P.Q.	24	tuff

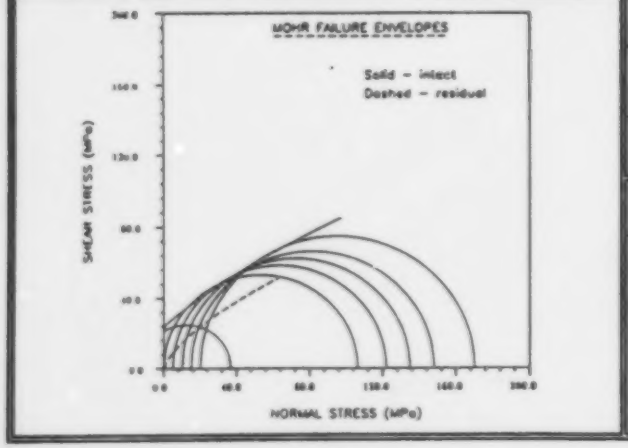
Regional Geology	Structural Characteristics
S-E of the Abitibi orogenic belt within the Malartic Group part of the Val d'Or and Dubuisson formation contact with batholith of Bourlamaque on west side	Dip: vertical Strike: 90° E Bedding Thickness: 200m Fracture Spacing: 1-1.5m Weathering: average to intense

Petrography

Structure: agglomerate	Composition
Texture: Grain Size: Colour: Grain Sorting: Grain Shape: Matrix:	carbonate, chlorite, sericite, quartz, (volcanic sediments)

Mechanical Properties

γ_d (Mg/m^3)	n %	ϕ (mm)	l (mm)	V_p (km/s)	V_s (km/s)	Q_c (MPa)	σ_t (MPa)	E (GPa)	ν	σ_3 (MPa)
2.74		47	110			106.38	-12.32	68.65	0.34	10.0-20.0



Hoek and Brown Material Constants

Q_c (MPa)	m	s	r^2	m_r	s_r	r^2_r
101.09	5.77	1.00	0.98	4.00	0.00	0.82

Borehole Information

Collar Elevation: -49m (1st level)
Depth: 9.3m
Inclination: horizontal
Latitude: 48° 8.4' N
Longitude: 77° 31' W

Table 1: Physical Rock Properties

Rock Type	Origin	Reference No./ Data Sheet	γ_d (Mg/m^3)	σ_t (MPa)	Q_u (MPa)	E (GPa)	ν	V_p(sat.) (km/s)	V_p(dry) (km/s)	n (%)
Amphibolite	Montauban Mine (P.Q.)	2/1	2.84	-25.96	163.47	73.21	0.28	-	-	<.1
Andesite	Chimo Mine (P.Q.)	19/2	2.80	-17.50	96.70	55.82	0.31			
Andesite	Hislop Township (Ont.)	3/3	2.90	-25.96	163.47	73.21	0.28	6.0	5.9	<.1
Andesite (foliated)	Kidd Creek Mine (Ont.)	22/49	2.82	-9.73				6.3		
Andesite	Kidd Creek Mine (Ont.)	22/50	3.05	-9.73	209.50	95.76	0.26	6.4		
Basalt	Béliveau Mine (Val d'Or, P.Q.)	24/51	2.85	-11.83	98.87	62.93	0.38			
Breccia	Hislop Township (Ont.)	3/4	2.89	-17.72	197.63	87.22	0.26			
Breccia (late granite)	Strathcona Mine (Levack, Ont.)	26/52	2.71	-17.77	362.97	84.31	0.27			
Coal	Lingan Mine (N.S.)	7/5	1.24	-0.43	9.78	1.76	0.34			
Conglomerate	Pamour Mine (Ont.)	20/6	2.76	-18.97	144.28	64.41	0.25			
Diabase (fine grained)	Lac St Jean (P.Q.)	9/8	2.97	-15.69	306.00	89.54	0.30	5.63	5.34	<.1
Diorite	Eldrich Mine (Evian, P.Q.)	10/9	2.85	-13.57	143.13	79.86	0.29	7.00	6.62	0.15
Diorite	Béliveau Mine (Val d'Or, P.Q.)	24/53	2.80	-16.87	146.11	70.26	0.34			

Table 1 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	γ_d (Mg/m^3)	σ_t (MPa)	Q_u (MPa)	E (GPa)	ν	V_p(sat.) (km/s)	V_p(dry) (km/s)	n (%)
Dolomite (Lockport)	Niagara Falls (Ont.)	15/-	2.38	-9.00	80.83	42.10	0.38	4.29	3.85	15.51
Dolomite (micritic)	Gays River Mine (N.S.)	25/54	2.73	-6.24	116.91	55.42	0.45			
Gneiss (Qz-Mica-Biotite)	Montauban Mine (P.Q.)	2/10	2.75	-12.00	93.17	41.72	0.25			
Gneiss (Qz-Biotite)	Montauban Mine (P.Q.)	2/11	2.69	-12.97	110.28	40.99	0.49			
Gneiss (mafic)	Strathcona Mine (Levack, Ont.)	26/55	2.93	-15.85	326.75	95.00	0.28			
Granite (pink)	Blue Beach North (NFLD.)	4/12	2.55	-11.53	223.86	63.61	0.27	4.57	5.17	1.43
Granite (pink, grey)	Pinawa (Man.)	11/13	2.63	-9.56	190.00	65.30	0.27		4.43	0.36
Granodiorite	Belmoral Mine (P.Q.)	17/14	2.78	-15.13	130.37	69.47	0.28	6.09	6.06	0.22
Greywacke	Pamour Mine (Ont.)	20/15	2.76	-14.89	134.10	44.20	0.29			
Greywacke (massive)	Gays River Mine (N.S.)	25/56	2.69	-15.93	236.72	60.81	0.26			
Limestone (bituminous)	Central Canada Potash (Sask.)	16/16	2.46	-5.43	56.37	29.80	0.30			
Limestone (fine grained)	Central Canada Potash (Sask.)	16/17	2.61	-9.40	125.70	40.08	0.26			
Limestone (oolitic)	Indiana (U.S.A.)	8/18	2.34	-4.76	59.70	40.80	0.25	3.87	3.80	13.76

Table 1 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	γ_d (Mg/m^3)	$sigma_t$ (MPa)	Q_u (MPa)	E (GPa)	ν	V_p(sat.) (km/s)	V_p(dry) (km/s)	n (%)
Limestone (sugary)	Central Canada Potash (Sask.)	16/19	2.20	-2.91	42.55	18.03	0.28			
Mafic Flow	Detour Lake Mine (Ont.)	5/20	2.95	-19.99	316.91	88.00	0.25	4.68	4.65	<.1
Mafic Flow Ore	Detour Lake Mine (Ont.)	5/21	2.99	-19.53	173.91	92.69	0.26			
Mudstone	Donkin-Morien Mine (N.S.)	13/22	2.61	-3.63	33.92	1.93	0.49			
Mudstone	Lingan Mine (N.S.)	7/23	2.70	-8.78	59.40	15.49	0.11			
Mudstone	Springhill Coal Mine (N.S.)	14/24		-6.21	26.71					
Mudstone (dolomitic)	Central Canada Potash (Sask.)	16/25	2.50	-6.39	44.31	9.34	0.15			
Norite	Creighton Mine (Ont.)	6/7	3.03	-11.53	203.40	59.74	0.18			
Phyllite	Lupin Mine (N.W.T.)	23/57	2.87	-20.89	120.60	52.30	0.21		4.98	
Quartzite (metagreywacke)	Lupin Mine (N.W.T.)	23/58	2.70	-13.68	168.06	49.19	0.42		3.54	
Rhyolite	Kidd Creek Mine (Ont.)	22/59	2.75	-12.48	111.98	80.75	0.39		6.16	
Sandstone	Lingan Mine (N.S.)	7/26	2.66	-6.87	80.02	30.37	0.18			
Sandstone (2nd Redbed)	Central Canada Potash (Sask.)	16/27	2.53	-2.91	24.90					

Table 1 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	γ_d (Mg/m^3)	σ_t (MPa)	Q_u (MPa)	E (GPa)	ν	V_p(sat.) (km/s)	V_p(dry) (km/s)	n (%)
Sandstone (fine grained)	Donkin-Morien (N.S.)	13/28	2.46	-8.96	121.25	19.04	0.14	4.89	4.43	1.36
Sandstone (fine grained)	Prince Mine (N.S.)	1/29	2.63	-9.97	142.87	41.79	0.18			
Sandstone (fine grained)	Springhill Coal Mine (N.S.)	14/30		-9.47	160.76	32.86	0.15			
Sandstone (Grimsby)	Niagara Falls (Ont.)	15/31	2.53	-8.98	168.20	24.88	0.36	4.25	3.30	6.60
Sandstone (med. grained)	Campbell's Quarry (Ont.)	21/32	2.40	-6.82	145.78	39.24	0.50	4.66	4.09	8.15
Sandstone (med. grained)	Donkin-Morien Mine (N.S.)	13/33	2.42	-7.46	88.23	20.38	0.21			
Sandstone (med. grained)	Prince Mine (N.S.)	1/34	2.31	-4.35	56.25	15.41	0.18			
Sandstone (med. grained)	Springhill Coal Mine (N.S.)	14/35		-5.91	83.30	24.00	0.20			
Sandstone (Whirlpool)	Niagara Falls (Ont.)	15/36	2.50	-11.61	146.42					
Shale	Prince Mine (N.S.)	1/37	2.60	-7.96	89.30	17.40	0.18			
Siltstone	Donkin-Morien Mine (N.S.)	13/38	2.68	-3.48	35.68	22.38	0.20			
Siltstone	Lingan Mine (N.S.)	7/39	2.70	-6.97	48.64	36.58	0.21			
Siltstone	Prince Mine (N.S.)	1/40	2.48	-5.59	82.08	14.16	0.17			

Table 1 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	γ_d (Mg/m^3)	σ_t (MPa)	Q_u (MPa)	E (GPa)	ν	V_p(sat.) (km/s)	V_p(dry) (km/s)	n (%)
Siltstone	Springhill Coal Mine (N.S.)	14/41		-6.14	177.20	30.00	0.14			
Sulphide Iron	Lupin Mine (N.W.T.)	23/60	3.21	-27.90	447.73	101.1	0.24		6.26	
Sulphide Ore	Copper Cliff S. Mine (Ont.)	12/42	2.99	-12.32	155.10	77.20	0.26	4.03	4.03	<.1
Sulphide Zinc	Kidd Creek Mine (Ont.)	22/61	3.72	-8.86	158.54	82.16	0.16		5.81	
Syenite	Hislop Township (Ont.)	3/43	2.66	-20.87	253.62	76.49	0.36	5.80	5.80	0.14
Talc-Carbonatee	Kidd Creek Minee (Ont.)	22/62	2.84	-3.17	33.34	28.55	0.58		4.85	
Talc-Chlorite	Detour Lake Mine (Ont.)	5/44	2.97	-9.58	92.43	50.82	0.34			
Talc-Chlorite Schist	Hislop Township- (Ont.)	3/45	2.84	-3.61	35.79	35.82	0.29			
Tonalite (Qz Diorite)	Eldrich Mine (P.Q.)	10/46	2.74	-13.54	123.42	73.58	0.23	6.30	6.27	0.14
Tuff	Bousquet Mine (P.Q.)	18/47	2.92	-9.95	50.83	58.79	0.29			
Tuff	Chimo Mine (P.Q.)	19/48	2.86	-19.91	165.92	95.49	0.23			
Tuff	Béliveau Mine (Val d'Or, P.Q.)	24/63	2.74	-12.32	106.38	68.65	0.34			

Table 2: Hoek and Brown Material Constants

Rock Type	Origin	Reference No./ Data Sheet	σ_3 Range (MPa)	σ_t (MPa)	Q_u (MPa)	Q_c (MPa)	Intact			Residual		
							m	s	r^2	m_r	s_r	r_r^2
Amphibolite	Montauban Mine (P.Q.)	2/1	5.0-20.0	-	-	170.06	21.36	1.00	1.00	3.05	0.00	0.66
Andesite	Chimo Mine (P.Q.)	19/2	5.0-20.0	-17.50	96.70	128.73	6.67	1.00	0.89	2.59	0.12	0.22
Andesite	Hislop Township (Ont.)	3/3	5.0-20.0	-25.96	163.47	226.12	7.75	1.00	0.79	-	-	-
Andesite (foliated)	Kidd Creek Mine (Ont.)	22/49	30.0-100.0	-9.73	-	59.88	1.04	1.00	0.87	-	-	-
Andesite	Kidd Creek Mine (Ont.)	22/50	30.0-100.0	-9.73	209.50	208.96	5.83	1.00	0.93	1.16	0.00	0.46
Basalt	Béliveau Mine (Val d'Or, P.Q.)	24/51	10.0-30.0	-11.83	98.87	84.87	3.26	1.00	0.82	1.02	0.008	0.67
Breccia	Hislop Township (Ont.)	3/4	5.0-20.0	-17.72	197.63	291.86	17.89	1.00	0.89	-	-	-
Breccia (late granite)	Strathcona Mine (Levack, Ont.)	26/52	5.0-20.0	-17.77	362.97	337.00	15.39	1.00	0.95	3.26	0.00	0.86
Coal	Lingan Mine (N.S.)	7/5	0.3-20.7	-0.43	9.78	20.96	20.26	1.00	0.95	-	-	-
Conglomerate	Pamour Mine (Ont.)	20/6	5.0-20.0	-18.97	144.28	126.36	4.07	1.00	0.84	3.51	0.00	0.24
Diabase (fine grained)	Lac St Jean (P.Q.)	9/8	3.5-20.7	-15.69	306.00	321.27	20.40	1.00	0.99	3.03	0.00	0.81
Diorite	Eldrich Mine (Evain, P.Q.)	10/9	1.0-20.0	-13.57	143.13	165.47	11.45	1.00	0.88	3.86	0.01	0.28
Diorite	Béliveau Mine (Val d'Or, P.Q.)	24/30	5.0-20.0	-16.87	146.11	132.95	5.05	1.00	0.95	1.89	0.00	0.53

Table 2 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	σ_3 Range (MPa)	σ_t (MPa)	Q_u (MPa)	Q_c (MPa)	Intact			Residual		
							m	s	r^2	m_r	s_r	r_r^2
Dolomite (micritic)	Gays River Mine (N.S.)	25/54	1.0-20.0	-6.24	116.91	108.97	11.94	1.00	0.97	5.70	0.00	0.98
Gneiss (Qz-Mica-Biotite)	Montauban Mine (P.Q.)	2/10	5.0-20.0	-12.00	93.17	103.21	7.57	1.00	0.98	4.78	0.40	0.01
Gneiss (Qz-Biotite)	Montauban Mine (P.Q.)	2/11	5.0-20.0	-12.97	110.28	103.20	5.68	1.00	0.97	2.27	0.02	0.33
Gneiss (mafic)	Strathcona Mine (Levack, Ont.)	26/55	5.0-20.0	-15.85	326.75	318.18	17.92	1.00	0.98	2.51	0.00	0.60
Granite (pink)	Blue Beach North (NFLD.)	4/12	10.0-30.0	-11.53	223.86	236.87	22.10	1.00	1.00	-	-	-
Granite (pink, grey)	Pinawa (Man.)	11/13	3.5-35.0	-9.56	190.00	234.15	27.75	1.00	0.99	2.26	0.00	0.97
Granodiorite	Belmoral Mine (P.Q.)	17/14	5.0-20.0	-15.13	130.37	125.37	6.64	1.00	0.97	3.64	0.00	0.15
Greywacke	Pamour Mine (Ont.)	20/15	5.0-20.0	-14.89	134.10	99.14	4.49	1.00	0.98	-	-	-
Greywacke (massive)	Gays River Mine (N.S.)	25/56	2.0-20.0	-15.93	236.72	244.28	15.25	1.00	0.98	2.81	0.00	0.86
Limestone (bituminous)	Central Canada Potash (Sask.)	16/16	0.1-27.6	-5.43	56.37	66.71	14.40	1.00	0.99	13.05	0.00	0.98
Limestone (fine grained)	Central Canada Potash (Sask.)	16/17	0.1-27.6	-9.40	125.70	127.97	12.76	1.00	0.98	7.02	0.00	0.87
Limestone (oolitic)	Indiana (U.S.A.)	8/18	6.9-34.5	-4.76	59.70	60.50	4.90	1.00	0.96	6.40	0.14	0.99
Limestone (sugary)	Central Canada Potash (Sask.)	16/19	0.1-27.6	-2.91	42.55	43.07	7.49	1.00	0.96	9.86	0.00	1.00

Table 2 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	σ_3 Range (MPa)	σ_t (MPa)	Q_u (MPa)	Q_c (MPa)	Intact			Residual		
							m	s	r^2	m_r	s_r	r_r^2
Mafic Flow	Detour Lake Mine (Ont.)	5/20	6.9-24.1	-19.99	319.91	287.22	12.27	1.00	0.95	5.01	0.00	0.98
Mafic Flow Ore	Detour Lake Mine (Ont.)	5/21	6.9-24.1	-19.53	173.91	199.22	10.87	1.00	0.94	5.36	0.00	0.56
Mudstone	Donkin-Morien Mine (N.S.)	13 22	0.4-5.2	-3.63	33.92	50.84	14.39	1.00	0.95	6.65	0.00	0.55
Mudstone	Lingan Mine (N.S.)	7/23	3.5-20.7	-8.78	59.40	55.85	3.26	1.00	0.98	5.59	0.00	0.98
Mudstone	Springhill Coal Mine (N.S.)	14/24	0.4-3.5	-6.21	26.71	39.35	4.44	1.00	0.56	9.83	0.08	0.44
Mudstone (dolomitic)	Central Canada Potash (Sask.)	16/25	0.1-27.6	-6.39	44.31	43.71	4.50	1.00	0.99	-	-	-
Norite	Creighton Mine (Sudbury, Ont.)	6/7	2.0-60.0	-11.53	203.40	222.67	17.14	1.00	0.95	5.40	0.04	0.49
Phyllite	Lupin Mine (N.W.T.)	23/57	10.0-30.0	-20.89	120.60	127.55	3.57	1.00	0.98	1.39	0.05	0.30
Quartzite (metagreywacke)	Lupin Mine (N.W.T.)	23/58	10.0-30.0	-13.68	168.06	148.16	6.81	1.00	0.94	1.29	0.00	0.60
Rhyolite	Kidd Creek Mine (Ont.)	22/59	10.0-100.0	-12.48	111.98	122.77	3.29	1.00	0.90	2.98	0.00	0.85
Sandstone	Lingan Mine (N.S.)	7/26	3.5-20.7	-6.87	80.02	80.25	13.68	1.00	0.98	3.00	0.00	0.79
Sandstone (2nd Redbed)	Central Canada Potash (Sask.)	16/27	0.1-27.6	-2.91	24.90	19.92	24.12	1.00	0.95	12.83	0.00	0.97
Sandstone (fine grained)	Donkin Morien Mine (N.S.)	13/28	0.4-5.2	-8.96	121.25	171.49	19.64	1.00	0.82	4.41	0.01	0.94

Table 2 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	σ_3 Range (MPa)	σ_t (MPa)	Q_u (MPa)	Q_c (MPa)	Intact			Residual		
							m_i	s	r^2	m_r	s_r	r_r^2
Sandstone (fine grained)	Prince Mine (N.S.)	1/29	0.3-20.7	-9.97	142.87	139.38	11.08	1.00	0.97	2.71	0.00	0.87
Sandstone (fine grained)	Springhill Coal Mine (N.S.)	14/30	0.4-3.5	-9.47	160.76	175.37	16.32	1.00	0.78	4.14	0.01	0.79
Sandstone (Grimsby)	Niagara Falls (Ont.)	15/31	3.5-35.0	-8.98	168.20	147.83	8.78	1.00	0.89			
Sandstone (med. grained)	Campbell's Quarry (Ont.)	21/32	10.0-30.0	-6.82	145.78	159.93	23.98	1.00	0.99	3.62	0.00	0.85
Sandstone (med. grained)	Donkin-Morien Mine (N.S.)	13/33	0.4-5.2	-7.46	88.23	94.00	10.64	1.00	0.95	2.79	0.01	0.75
Sandstone (med. grained)	Prince Mine (N.S.)	1/34	0.3-20.7	-4.35	56.25	49.42	12.49	1.00	0.97	3.87	0.00	0.87
Sandstone (med. grained)	Springhill Coal Mine (N.S.)	14/35	0.4-3.5	-5.91	83.30	93.94	16.72	1.00	0.94	4.70	0.01	0.80
Sandstone (Whirlpool)	Niagara Falls (Ont.)	15/36	3.5-35.0	-11.61	146.42	170.15	14.84	1.00	0.90	-	-	-
Shale	Prince Mine (N.S.)	1/37	0.3-20.7	-7.96	89.30	69.53	9.39	1.00	0.96	3.37	0.00	0.99
Siltstone	Donkin-Morien Mine (N.S.)	13/38	0.4-5.2	-3.48	35.68	36.36	8.95	1.00	1.00	4.41	0.01	0.94
Siltstone	Lingan Mine (N.S.)	7/39	3.5-20.7	-6.97	48.64	45.35	3.92	1.00	0.94	4.43	0.03	0.86
Siltstone	Prince Mine (N.S.)	1/40	0.3-20.7	-5.59	82.08	63.26	11.24	1.00	1.00	2.86	0.00	0.95
Siltstone	Springhill Coal Mine (N.S.)	14/41	0.4-3.5	-6.14	177.20	189.38	30.61	1.00	0.97	3.34	0.00	1.00

Table 2 - (cont'd)

Rock Type	Origin	Reference No./ Data Sheet	σ_3 Range (MPa)	σ_t (MPa)	Q_w (MPa)	Q_c (MPa)	Intact			Residual		
							m	s	r^2	m_r	s_r	r_r^2
Sulphide Iron	Lupin Mine (N.W.T.)	23/60	10.0-30.0	-7.73	447.73	515.26	16.78	1.00	0.82	-	-	-
Sulphide Ore	Copper Cliff South Mine (Ont.)	12/42	1.0-10.3	-12.32	155.10	175.66	17.49	1.00	0.84	6.43	0.06	0.92
Sulphide Zinc	Kidd Creek Mine (Ont.)	22/61	10.0-100.0	-8.86	158.54	157.47	2.80	1.00	0.71	2.88	0.30	0.75
Syenite	Hislop Township (Ont.)	3/43	5.0-20.0	-20.87	253.62	179.25	7.65	1.00	0.94	-	-	-
Talc-Carbonate	Kidd Creek Mine (Ont.)	22/62	10.0-100.0	-3.17	33.34	27.64	2.27	1.00	0.92	0.06	0.30	-
Talc-Chlorite	Detour Lake Mine (Ont.)	5/44	6.9-24.1	-9.58	92.43	79.56	4.65	1.00	0.92	3.22	0.00	0.85
Talc-Chlorite-Schist	Hislop Township (Ont.)	3/45	5.0-20.0	-3.61	35.79	33.37	6.70	1.00	0.98	0.24	0.00	0.99
Tonalite (Qz-Diorite)	Eldrich Mine (P.Q.)	10/46	1.0-20.0	-13.54	123.42	138.72	10.92	1.00	0.74	4.42	0.04	0.36
Tuff	Bousquet Mine (P.Q.)	18/47	5.0-20.0	-9.95	50.83	54.78	3.72	1.00	0.95	2.72	0.04	0.17
Tuff	Chimo Mine (P.Q.)	19/48	5.0-20.0	-19.91	165.92	185.43	9.23	1.00	0.93	2.63	0.00	0.62
Tuff	Béliveau Mine (Val d'Or, P.Q.)	24/63	10.0-20.0	-12.32	106.38	101.09	5.77	1.00	0.98	4.00	0.00	0.82

Table 3 - List of MRL reports referred to in Data Sheets and Tables 1 and 2

Reference Number	Mine Name	Location	Report Number	Title	Authors	Data Sheet
1	Prince Mine	Cape Breton	86-33(INT)	Strength Determination of Prince Mine Rocks	B. Gorski	29,34, 37,40
			85-128(INT)	Strength Determination of Prince Mine Rocks	B. Gorski	
2	Montauban Mine	Quebec	87-169(TR)	Strength Determination of Montauban Mine Rocks	B. Gorski, M. Little, M.C. Betournay	1,10, 11
3	Hislop Township	Ontario	88-77(INT)	Strength Determination of Hislop Township Deposit Rocks	B. Gorski	3,4,43, 45
4	Blue Beach North	Newfoundland	88-74(INT)	Strength Determination of Blue Beach North Deposit Rocks	B. Gorski	12
5	Detour Lake Mine	Ontario	85-45(INT)	Strength Determination of Detour Lake Mine Rocks	B.Gorski	20,21, 44
			85-108(INT)	Additional Strength Determinations of Detour Lake Mine Rocks		
6	Creighton Mine	Ontario	88-18(INT)	Rock Material Constants in Function of Stress Path Dependancy Using a Computer Controlled Servo-Hydraulic Test System	B. Gorski	7
7	Lingan Mine	Cape Breton	86-34(INT)	Uniaxial Strength Determinations of Lingan Mine Rocks	B. Gorski	5,23,26, 39
8	Indiana	USA	83-99(TR)	Triaxial Properties of Indiana Limestone	M. Betournay, T. Shimotani	18
9	Lac St Jean	Quebec	83-19(INT)	Evaluation of Testing Procedures for Minimizing Rock Sample Requirement	T. Shimotani	8
10	Eldrich Mine	Evain, P.Q.	88-34(INT)	Strength Determination of Eldrich Mine Rocks	B. Gorski	9,46
			88-111(INT)	Strength Determination of Eldrich Mine Rocks - Phase II	B. Gorski, M. Little	

Table 3 (cont'd)

Reference Number	Mine Name	Location	Report Number	Title	Authors	Data Sheet
11	Pinawa	Manitoba	84-48(TR)	Mechanical Properties of Samples from Pinawa, Manitoba	A. Annor	13
12	Copper Cliff South Mine	Ontario	82-141(INT)	Stiff Triaxial Tests on Copper Cliff South Mine Orebody Rock	J. Molson	42
13	Donkin-Morien	Cape Breton	84-90(TR)	A Study of Rock Behaviour for the Donkin-Morien Rock/Support Interaction Contract	M. Betournay	22,28, 33,38
14	Springhill Coal Mine	Cape Breton	84-89(TR)	Strength and Deformation of Various Rocks from the Springhill Coal Mine, Nova Scotia	M. Betournay	24,30, 35,41
15	Niagara Falls	Ontario	85-134(TR)	Preliminary Results of High Temperature and High Pressure Triaxial Testing on Ontario Hydro Specimens	R. Jackson	31,36
16	Central Canada Potash	Saskatchewan	85-124(INT)	Strength Determination of Central Canada Potash Rocks	B. Gorski	16,17,19 25,27
17	Belmoral Mine	Quebec	88-136(INT) 89-22(INT)	Strength Determination of Belmoral Mine Rocks Strength Determinations of Belmoral, Pamour, Chimo and Bousquet Mine Rocks	B. Gorski and M. Little B. Gorski, G. Murray, S. Schlueter	14
18	Bousquet Mine	Quebec	89-22(INT)	Strength Determinations of Belmoral, Pamour, Chimo and Bousquet Mine Rocks	B. Gorski, G. Murray, S. Schlueter	47
19	Chimo Mine	Quebec	89-22(INT)	Strength Determinations of Belmoral, Pamour, Chimo and Bousquet Mine Rocks	B. Gorski, G. Murray, S. Schlueter	2,48
20	Pamour Mine	Ontario	89-22(INT)	Strength Determinations of Belmoral, Pamour, Chimo and Bousquet Mine Rocks	B. Gorski, G. Murray, S. Schlueter	6,15
21	Campbell's Quarry	Ontario	89-118(TR)	The Geological and Engineering Classification of Nepean Sandstone	B. Gorski	32

Table 3 (cont'd)

Reference Number	Mine Name	Location	Report Number	Title	Authors	Data Sheet
22	Kidd Creek Mine No. 3	Timmins, Ont.	90-097(TR)	Strength Determinations of Kidd Creek Mine No. 3 Rocks	B. Gorski	49,50,59, 61,62
23	Lupin Mine	Contwoyto Lake, N.W.T.	90-100(TR)	Strength Determinations of Lupin Mine Rocks	B. Gorski	57,58,60
24	Lucien C. Béliveau	Val d'Or, P.Q.	90-113(TR)	Strength Determinations of Lucien C. Béliveau Mine Rocks	B. Gorski	51,53,63
25	Gays River Mine	Gays River, N.S.	91-004(TR)	Strength Determinations of Gays River Mine Rocks	B. Gorski, J. Folta	54,56
26	Strathcona Mine	Levack, Ont.	90-133(INT)	Strength Determinations of Strathcona Mine Rocks	B. Gorski	52,55

		ESSENTIAL MINERALS	POTASH FELDSPAR > ⅔ TOTAL FELDSPAR			POTASH FELDSPAR ⅓–⅔ TOTAL FELDSPAR			POTASH FELDSPAR < ⅓ TOTAL FELDSPAR	
			QUARTZ >10%	QUARTZ <10% FELDSPATHOID <10%	FELDSPATHOID >10%	QUARTZ >10%	QUARTZ <10% FELDSPATHOID <10%	FELDSPATHOID >10%	POTASH FELDSPAR >10% TOTAL FELDSPAR QUARTZ >10%	QUA
		CHARACTERIZING ACCESSORY MINERALS	CHIEFLY: HORNBLENDE, BIOTITE, PYROXENE, MUSCOVITE ALSO: SODIC AMPHIBOLES, AEGIRINE, CANCRINITE, SODALITE, TOURMALINE			CHIEFLY: HORNBLENDE, BIOTITE, PYROXENE ALSO: SODIC AMPHIBOLES, AEGIRINE			CHIEFLY: ALSO:	
		COLOR INDEX	10	15	20	20	25	30	20	
		AVERAGE CHEMICAL COMPOSITION (DALY) SiO_2	71.5	60.4	56.0	66.8	57.0	54.1	65.3	
		Al_2O_3	14.0	17.0	19.2	15.6	17.1	21.0	16.1	
		Fe_2O_3	1.5	2.7	2.9	2.3	3.4	1.8	2.1	
		FeO	1.4	2.9	1.6	1.3	3.6	3.3	2.3	
		MgO	0.6	1.8	0.6	1.0	2.3	1.1	1.7	
		CaO	1.6	3.7	2.0	2.8	5.4	3.2	3.9	
		Na_2O	3.4	4.2	8.5	3.7	4.7	6.2	3.8	
		K_2O	4.3	5.1	5.3	4.2	3.7	5.9	2.7	
PHANERITIC	EQUIGRANULAR Batholiths, lopoliths, stocks, large laccoliths, thick dikes, and sills		GRANITE ALASKITE—few dark minerals GRAPHIC GRANITE—graphic texture ALKALI GRANITE—abundant albite and sodic amphibole or pyroxene CHARNOCKITE—with orthopyroxene LUDULLIANITE—tourmalinized	SYENITE QUARTZ SYENITE—a little quartz ALKALI SYENITE—no plagioclase except albite PULASKITE—a little nepheline NORDMARKITE—a little quartz LARVIKITE—with "blue" feldspar SHONKINITE—abundant Fe/Mg minerals	NEPHELINE SYENITE LEUCITE SYENITE—pseudoleucite only feldspathoid SODALITE SYENITE—sodalite only feldspathoid FOYAITE—abundant feldspar MALIGNITE—abundant Fe/Mg minerals DITROITE—with nepheline and sodalite	QUARTZ MONZONITE (ADAMELLITE)	MONZONITE	NEPHELINE MONZONITE	GRANODIORITE	QUA
PORPHYRITIC	PHANERITIC GROUNDMASS Laccoliths, dikes, sills, plugs, small stocks, margins of larger masses		GRANITE PORPHYRY	SYENITE PORPHYRY	NEPHELINE SYENITE PORPHYRY	QUARTZ MONZONITE PORPHYRY	MONZONITE PORPHYRY	NEPHELINE MONZONITE PORPHYRY	GRANODIORITE PORPHYRY	QUA
PORPHYRITIC	APHANITIC GROUNDMASS Dikes, sills, laccoliths, surface flows, margins of larger masses, welded tuffs		RHYOLITE PORPHYRY	TRACHYTE PORPHYRY	PHONOLITE PORPHYRY	QUARTZ LATITE PORPHYRY	LATITE PORPHYRY	NEPHELINE LATITE PORPHYRY	DACITE PORPHYRY	
APHANITIC	MICROCRYSTALLINE Dikes, sills, surface flows, margins of larger masses, welded tuffs		RHYOLITE	TRACHYTE	PHONOLITE LEUCITE PHONOLITE (Leucite trachyte)—leucite only feldspathoid TINGUAITE—abundant aegirine WYOMINGITE—leucite and phlogopite	QUARTZ LATITE (DELLENITE)	LATITE (TRACHY-ANDESITE)	NEPHELINE LATITE	DACITE	
APHANITIC	GLASSY Surface flows, margins of dikes and sills, welded tuffs		OBSIDIAN—black PITCHSTONE—resinous VITROPHYRE—porphyritic PERLITE—concentric fractures PUMICE—finely cellular, light colored SCORIA—coarsely cellular, dark colored			Normally it is not possible to determine the composition of these rocks. They are customarily designated by the names at the left of this column. Basic glass is rare so rocks named, except scoria, will normally be silicic. If the approximate composition (by close association) or silica content (by refractive index or analysis), can be determined, the name may be prefixed by the name of the appropriate aphanitic rock, for example, "trachyte obsidian," or "latite vitrophyre." In general, scoria is basic; basic obsidian is called "tachylite", and spherulitic tachylite is "variolite."			

CLASSIFICATION OF IGNEOUS ROCKS

Russell B. Travis

PLAGIOCLASE FELDSPAR > ⅔ TOTAL FELDSPAR					LITTLE OR NO FELDSPAR		SPECIAL TYPES
FELDSPAR OTAL AR TZ > 10%	POTASH FELDSPAR < 10% TOTAL FELDSPAR				CHIEFLY PYROXENE AND/OR OLIVINE	CHIEFLY FERRO-MAGNESIAN MINERALS AND FELDSPATHOIDS	
	SODIC PLAGIOCLASE		CALCIC PLAGIOCLASE				
	QUARTZ > 10%	QUARTZ < 10% FELDSPATHOID < 10%	QUARTZ < 10% FELDSPATHOID < 10%	FELDSPATHOID > 10% PYROXENE > 10%			
	CHIEFLY HORNBLENDE, BIOTITE, PYROXENE (IN ANDESITE) ALSO PYROXENE FELDSPATHOID SODIC AMPHIBOLES		CHIEFLY PYROXENE URALITE, OLIVINE ALSO HORNBLENDE, BIOTITE, QUARTZ, ANALCITE, AEGIRINE, SODIC AMPHIBOLES		CHIEFLY SERPENTINE, IRON ORE ALSO HORNBLENDE, BIOTITE	HORNBLENDE BIOTITE IRON ORE	
20	20	25	50	60	95	55	
65 3 16 1 2 1 2 3 1 7 3 9 3 8 2 7	61 6 16 2 2 5 3 8 2 8 5 4 3 4 2 1	58 2 17 0 3 2 3 7 3 5 6 3 3 5 2 1	48 6 16 8 4 8 6 0 5 1 8 9 3 7 1 9	47 4 15 4 4 9 5 4 5 0 9 7 3 8 3 5	41 1 4 8 4 0 7 1 32 2 4 4 0 5 1 0	42 0 17 9 5 7 5 7 3 4 10 3 8 0 2 4	
ORORITE	QUARTZ DIORITE (TONALITE)	DIORITE	GABBRO GABBRO—with clinopyroxene NORITE—with orthopyroxene OLIVINE GABBRO—with olivine TROCTOLITE—olivine and plagioclase only ANORTHOSITE—plagioclase only QUARTZ GABBRO—with quartz	DIABASE (Dolerite of British) Phaneritic diabasic texture, normally medium or fine-grained	THERALITE ESSEXITE, NEPHELINE GABBRO TESCHENITE—analcite only interstitial OLIVINE THERALITE—with olivine	PERIDOTITE PERIDOTITE—clinopyroxene and olivine HARZBURGITE—orthopyroxene and olivine PICRITE—pyroxene and olivine with some plagioclase DUNITE—olivine only PYROXENITE—pyroxene only SERPENTINE (SERPENTINITE)—chiefly serpentine	ANDESURITE—pyroxene, olivine, and plagioclase LIDITE—pyroxene and olivine PERIDOTITE—pyroxene and plagioclase LHERZOLITE, SHELAITE PYROXENITE—pyroxene and olivine	PEGMATITE—phanerocrystalline, normally silicic, dike rock (or small irregular mass) having a conspicuously coarser texture than porsee. APLITE—phanerocrystalline rock having sugary (fine-grained allotriomorphic-granular) texture. LAMPROPHYRE—dark dike rock with enclosure fully phenocrysts and/or in the ground fully minerals or glassy mass.
HORITE PHYRY	QUARTZ DIORITE PORPHYRY	DIORITE PORPHYRY	GABBRO PORPHYRY	THERALITE PORPHYRY	PERIDOTITE PORPHYRY KIMBERLITE—peridotite porphyry or breccia		
DACITE PORPHYRY		ANDESITE PORPHYRY	BASALT PORPHYRY	TEPHRITE PORPHYRY	LAMPROPHYRE PORPHYRY		TRAP—dark-colored aphanitic rock. FELSITE—light-colored aphanitic rock.
DACITE		ANDESITE	BASALT OLIVINE BASALT—with olivine ANALCITE BASALT—with analcite QUARTZ BASALT—with quartz OCEANITE—with abundant olivine	TEPHRITE LEUCITE TEPHRITE—leucite only interstitial BASANITE—with olivine LEUCITE BASANITE—with olivine and leucite	LAMPROPHYRE	NEPHELINITE—pyroxene and nepheline LEUCITITE—pyroxene and leucite MELILITITE—pyroxene and melilite OLIVINE NEPHELINITE (NEPHELINE BASALT)—pyroxene, nepheline, and olivine ETC	

FREQUENCY OF OCCURRENCE

This size type indicates COMMON ROCKS.
This size type indicates UNCOMMON ROCKS.
This size type indicates RARE ROCKS.

	TEXTURE →	GRAIN SIZE <1/256 mm.		GRAIN SIZE 1/256-2 mm.			
		CRYSTALLINE, CLASTIC OR AMORPHOUS		CRYSTALLINE, CLASTIC, BIOCLASTIC, OOLITIC, ETC.		UNCONSOLI	
	COMPOSITION OF MAJOR FRACTION →	Composition as Indicated in left column (prefix appropriate names for mixtures)	Clay Minerals or Clay-Size Material	Composition as Indicated in left column (prefix appropriate names for mixtures)	Chiefly Calcite or Dolomite	Chiefly >90% Quartz	Chiefly Feldspar
COMPOSITION OF MINOR FRACTION	<10% Minor Fraction				LIMESTONE DOLOMITE ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	QUARTZ SANDSTONE (Quartzose sandstone)	FELDSPATHI
	Clay Minerals or Clay-Size Materials	CLAYSTONE—massive, blocky structure MUDSTONE—indurated mud. Includes claystone and siltstone. SHALE—finely fissile. May include much silt. CLAY SHALE (Argillaceous shale)—chiefly clay minerals. ARGILLITE—highly indurated. Incipiently recrystallized. BENTONITE—swells and disaggregates in water.			ARGILLACEOUS LIMESTONE ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	ARGILLACEOUS QUARTZ SANDSTONE	ARGILLACEOUS PATHIC SI LOESS—fine Massive, po
	SILICA Opal Chalcedony Quartz	CHERT—cryptocrystalline or opal. Nodular, nodular, massive. DIATOMITE (Diatomaceous earth)—diatom tests. RADIOLARITE (Tripoli, in part)—radiolarian tests. FLINT—very dense, fissile. PORCELLANITE—argillaceous or silty chert.	SILICEOUS SHALE = CLAYSTONE = MUDSTONE ETC.	SILICEOUS OOLITE—>50% oolitic OOLITIC CHERT—<50% oolitic DIATOMITE—diatom tests RADIOLARITE—radiolarian tests	SILICEOUS LIMESTONE—disseminated silica CHERTY LIMESTONE—containing chert nodules ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	ORTHOQUARTZITE (Sedimentary quartzite) (Siliceous quartz sandstone)	FELDSPATHIC S (Siliceous
	CALCITE OR DOLOMITE	LIMESTONE—chiefly calcite, massive. DOLOMITE (Dolostone)—chiefly dolomite, massive. CHALK—chalky texture. TUFA—very porous, friable. TRAVERTINE—banded, cohesive, denser than tufa. CALICHE—lime-rich deposit formed near surface.	CALCAREOUS SHALE (Limy shale) etc. MARLSTONE 25-75% carbonate	LIMESTONE — chiefly calcite, crystalline DOLOMITE (Dolostone) — chiefly dolomite, crystalline CLASTIC LIMESTONE (Calcarenite or calcite sandstone) — clastic CALCAREOUS OOLITE — > 50% oolitic OOLITIC LIMESTONE — < 50% oolitic ORGANIC LIMESTONE — Richly fossiliferous		CALCAREOUS QUARTZ SANDSTONE	CALCAREOUS SANDSTONE
	IRON MINERALS Chiefly: Limonite Siderite Goethite Chamosite Hematite	HEMATITE ROCK—massive, fossiliferous LIMONITE ROCK—massive, fossiliferous IRON SHALE ROCK—earthy, impure, fossiliferous SIDERITE ROCK (Clay ironstone)—an indurated mixture of iron, silica, clay, and carbonate SIDERITE—fine, carbonated—massive	LIMONITIC or HEMATITIC (Ferruginous) SHALE ETC.	HEMATITE OOLITE—>50% oolitic LIMONITE OOLITE—>50% oolitic OOLITIC IRON ROCK—<50% oolitic SIDERITE—fine carbonate—chiefly siderite, crystalline	LIMONITIC or HEMATITIC (Ferruginous) LIMESTONE ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	LIMONITIC or HEMATITIC (Ferruginous) QUARTZ SANDSTONE	LIMONITIC or (Ferruginous SANDSTONE
	CARBON Humus-Yields carbonaceous derivatives Sapropel-Yields bituminous derivatives	COAL BITUMINOUS—Hackly fracture ANTHRACITE—conchoidal fracture ASPHALT—aphaltic GILSONITE—black, high lustre, amorphous	BITUMINOUS SHALE, ETC.—carbonized marls. OIL SHALE (Oil shale) ETC.—asphaltic	PEAT—dark semi-carbonized plant remains LIGNITE—brown-black well-carbonized plant remains	CARBONACEOUS LIMESTONE BITUMINOUS LIMESTONE ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	CARBONACEOUS QUARTZ SANDSTONE BITUMINOUS QUARTZ SANDSTONE	CARBONACEOUS SANDSTONE BITUMINOUS SANDSTONE
	MISCELLANEOUS Phosphate (Collophane) Evaporites Halite and Sylvite Anhydrite Gypsum	PHOSPHORITE—phosphate rock. ROCK SALT—massive halite or sylvite ROCK ANHYDRITE—massive anhydrite ROCK GYPSUM—massive gypsum	PHOSPHATIC SHALE, ETC.	PHOSPHATIC OOLITE—>50% oolitic ROCK SALT—crystalline ROCK ANHYDRITE—crystalline ROCK GYPSUM—crystalline GYPSUM SAND—clastic	PHOSPHATIC LIMESTONE ETC. All varieties in the Calcite-Dolomite horizontal column are possible here.	PHOSPHATIC QUARTZ SANDSTONE ETC.	PHOSPHATIC SANDSTONE ETC.

The names in the above chart are root names and should be preceded by appropriate terms for any significant feature of the rock. The proper order is color, structure, grain size (sandstones only), minor constituents, cement, and root name. Structure includes, for example, "thin-bedded," "massive," "cross-bedded," "thinly laminated," etc. The size grade for conglomerates should immediately precede "conglomerate." Some common nonmineral minor constituent terms are "tuffaceous," "cherty," "fossiliferous," "oolitic," "coralline," "clayey (argillaceous)," "silty," "shaly," "sandy (arenaceous)," and "conglomeratic." Minor mineralogy should follow the nonmineral composition and should be restricted to one conspicuous mineral not implied in the root name. It should be applied in adjective form as "micaceous," "chloritic," "glauconitic," and "pyritic." The most common cement terms are given in the chart with the root names. Some typical rock names are "black thin-bedded

CLASSIFICATION OF SEDIMENTARY ROCKS

By Russell B. Travis

1/256-2 mm.

CLASTIC

UNCONSOLIDATED - silt, sand — CONSOLIDATED - siltstone, sandstone

SIZE GRADES (mm.) 1/256 - 1/16, silt; 1/16 - 1/8 very fine sand; 1/8 - 1/4, fine sand; 1/4 - 1/2, medium sand; 1/2 - 1, coarse sand; 1-2, very coarse sand

Chiefly Quartz		Quartz and >25% Feldspar	Quartz, Feldspar, Rock Chips, Pelitic Matrix, Angular grains, Tough.	Volcanic Ejecta
Feldspar 10-25%	Rock Chips >10%			
FELDSPATHIC SANDSTONE	LITHIC SANDSTONE	ARKOSE (Arkosic sandstone) Normally pink, red or light gray	GRAYWACKES—normally greenish gray SUBGRAYWACKES—low in feldspar, rock chips, or less angular grains. Tendency to chemical cement	ASH—unconsolidated fragments under 4 mm TUFF—consolidated ash VOLCANIC BRECCIA—angular fragments over 4 mm AGGLOMERATE—large proportion (>25%) of bombs These rocks are classified on the proportions of vitric, crystal (mineral), or lithic material they contain, for example: "vitric lithic ash," or "crystal vitric tuff." If the mineralogy of the crystal or lithic fragments can be determined, the name of the appropriate volcanic rock can be prefixed as, "rhyolite vitric crystal tuff," or simply, "rhyolite tuff."
ARGILLACEOUS FELDSPATHIC SANDSTONE LOESS—fine sand or silt. Massive, porous, coherent	ARGILLACEOUS LITHIC SANDSTONE	ARGILLACEOUS ARKOSE	ARGILLACEOUS GRAYWACKE ARGILLACEOUS SUBGRAYWACKE	
FELDSPATHIC ORTHOQUARTZITE (Calcareous feldspathic sandstone)	LITHIC ORTHOQUARTZITE (Calcareous lithic sandstone)	SILICEOUS ARKOSE (Quartzose arkose)	SILICEOUS SUBGRAYWACKE	
CALCAREOUS FELDSPATHIC SANDSTONE	CALCAREOUS LITHIC SANDSTONE	CALCAREOUS ARKOSE	CALCAREOUS SUBGRAYWACKE	
LIMONITIC or HEMATITIC (Ferruginous) FELDSPATHIC SANDSTONE	LIMONITIC or HEMATITIC (Ferruginous) LITHIC SANDSTONE	LIMONITIC or HEMATITIC (Ferruginous) ARKOSE	LIMONITIC or HEMATITIC (Ferruginous) GRAYWACKE LIMONITIC or HEMATITIC (Ferruginous) SUBGRAYWACKE	
CARBONACEOUS FELDSPATHIC SANDSTONE BITUMINOUS FELDSPATHIC SANDSTONE	CARBONACEOUS LITHIC SANDSTONE BITUMINOUS LITHIC SANDSTONE	CARBONACEOUS ARKOSE BITUMINOUS ARKOSE	CARBONACEOUS GRAYWACKE ETC. CARBONACEOUS SUBGRAYWACKE ETC.	
PHOSPHATIC FELDSPATHIC SANDSTONE ETC.	PHOSPHATIC LITHIC SANDSTONE ETC.	PHOSPHATIC ARKOSE ETC.	PHOSPHATIC SUBGRAYWACKE ETC.	

GRAIN SIZE >2 mm.

CLASTIC

UNCONSOLIDATED - gravel (rounded), rubble (angular)
CONSOLIDATED - conglomerate (rounded), brecciа (angular)
SIZE GRADES (mm.) - 2-4, granules; 4-64, pebbles; 64-256 cobbles; >256 boulders

CHIEFLY ONE CONSTITUENT Especially quartz, chert, or quartzite. Also shale or limestone. Homogeneous conglomerates and breccias.	SEVERAL CONSTITUENTS Usually including unstable constituents. Mixed conglomerates and breccias.
Name consists of chief constituent and size grade, for example QUARTZ PEBBLE CONGLOMERATE CHERT COBBLE CONGLOMERATE LIMESTONE PEBBLE BRECCIA ETC	Name consists of "mixed" or "polycomponent" and size grade, for example: MIXED PEBBLE CONGLOMERATE or MIXED COBBLE CONGLOMERATE Name may exclude composition as GRAYWACKE-ANDESITE-CHERT PEBBLE CONGLOMERATE
ARGILLACEOUS (rock, grade) CONGLOMERATE—uncommon with stable constituent	ARGILLACEOUS MIXED (grade) CONGLOMERATE GLACIAL TILL—chaotic mixture of clay, sand and gravel TILLITE—indurated till FANGLOMERATE—alluvial fan material
SILICEOUS (rock, grade) CONGLOMERATE (Orthoquartzitic (rock, grade) conglomerate)	SILICEOUS MIXED (grade) CONGLOMERATE
CALCAREOUS (rock, grade) CONGLOMERATE	CALCAREOUS MIXED (grade) CONGLOMERATE
LIMONITIC or HEMATITIC (Ferruginous) (rock, grade) CONGLOMERATE	LIMONITIC or HEMATITIC (Ferruginous) MIXED (grade) CONGLOMERATE
CARBONACEOUS (rock, grade) CONGLOMERATE BITUMINOUS (rock, grade) CONGLOMERATE	CARBONACEOUS MIXED (grade) CONGLOMERATE BITUMINOUS MIXED (grade) CONGLOMERATE
PHOSPHATIC (rock, grade) CONGLOMERATE	PHOSPHATIC MIXED (grade) CONGLOMERATE

one conspicu... be applied ir... etc," and "py... the chart with ...k thin-bedded

micaceous shale" "gray massive medium-grained glauconitic quartz sandstone" "tan siliceous quartz pebble conglomerate," and "white vuggy foraminiferal limestone"

Graywacke currently has two meanings. To some it denotes a ... sugar quartz sandstone with more than 20 (or 15) percent pe... matrix. To many others, it has retained its original meaning, ... is a very hard, firm sandstone without porosity or chemical ... In addition, these "true" graywackes typically have ex... angular grains, a pelitic matrix, and a dark color

FREQUENCY OF OCCURRENCE
This size type indicates **COMMON ROCKS.**
This size type indicates **UNCOMMON ROCKS.**
This size type indicates **RARE ROCKS.**

COLOR	CHIEF MINERALS	CHARACTERIZING ACCESSORY MINERALS	NONDIRECTIONAL STRUCTURE Massive or Granulose	
			Contact Metamorphism*	
			Fine Grained (Aphanitic)	Medium or Coarse Grained (Phaneritic)
LIGHT	QUARTZ FELDSPAR CALCITE DOLOMITE TALC MUSCOVITE SERICITE	Muscovite Sericite Sillimanite Kyanite Cordierite Tremolite Wollastonite Albite Andalusite Garnet Phlogopite Diopside Enstatite Staurolite Glaucophane Anthophyllite Pyrophyllite Chloritoid Actinolite Tourmaline Epidote Chiastolite Olivine Serpentine Chlorite Biotite Graphite Chondrodite Scapolite	METAQUARTZITE MARBLE BRUCITE MARBLE SOAPSTONE—chiefly talc HORNFELS—any metamorphic rock with nondirectional structure	METAQUARTZITE MARBLE BRUCITE MARBLE TREMOLITE MARBLE WOLLASTONITE MARBLE TREMOLITE HORNFELS WOLLASTONITE HORNFELS CALC-SILICATE HORNFELS—chiefly calc-silicate minerals
INTERMEDIATE (Includes Red or Brown)	ABOUT EQUAL PROPORTIONS OF LIGHT-COLORED AND DARK-COLORED MINERALS		METAQUARTZITE MARBLE SKARN—pyroxene-garnet-carbonate hornfels SOAPSTONE—chiefly talc HORNFELS—any metamorphic rock with nondirectional structure SERPENTINE*	METAQUARTZITE MARBLE DIOPSIDE MARBLE CHONDRODITE MARBLE ANDALUSITE HORNFELS SKARN—pyroxene-garnet-carbonate hornfels GARNET HORNFELS KYANITE HORNFELS ANTHOPHYLLITE HORNFELS CALC-SILICATE HORNFELS SERPENTINE* CORDIERITE-ANTHOPHYLLITE HORNFELS
DARK (Includes Green)	QUARTZ CALCITE DOLOMITE FELDSPAR CHLORITE HORNBLENDE SERPENTINE BIOTITE PYROXENE ACTINOLITE EPIDOTE OLIVINE MAGNETITE		METAQUARTZITE MARBLE SKARN—pyroxene-garnet-carbonate hornfels GRAPHITE MARBLE CHLORITE MARBLE SERPENTINE MARBLE (Ophicalcite) HORNFELS—any metamorphic rock with nondirectional structure SERPENTINE*	METAQUARTZITE MARBLE GRAPHITE MARBLE CHLORITE MARBLE OLIVINE MARBLE SKARN—pyroxene-garnet-carbonate hornfels ACTINOLITE MARBLE ACTINOLITE-EPIDOTE HORNFELS ACTINOLITE HORNFELS PYROXENE HORNFELS EPIDOTE HORNFELS TOURMALINE HORNFELS ANDALUSITE-CHIASTOLITE HORNFELS SERPENTINE* ECLOGITE—garnet-amphibole hornfels MAGNETITE ROCK CORDIERITE HORNFELS AMPHIBOLITE—chiefly hornblende and or plagioclase

Mechanical Metam…	
Cataclasti…	
These rocks are formed by one … only minor recrystallization. If … coarse, directional features, the … breccia" if coarse grained, and … grained. Most of them, however, …	
MYLONITE—finely gr…	
FLASER GRANITE, FL…	
FLASER CONGLOM…	
flaser structure	
AUGEN GNEISS—augen…	
ULTRAMYLONITE—garnetty …	
Rocks with only minor deform… "schistose," for example … "schistose rhyolite," etc., but … metamorphic rocks	

As can be noted from the chart, naming a metamorphic rock consists chiefly of prefixing the structural term with mineral names or an appropriate rock name. The rock name indicates either the original rock, if recognizable, or the new mineral composition. The prefix "meta," as "metagabbro," "metasandstone," "metatuff," etc., is applied to rocks that have undergone considerable recrystallization but have largely retained their original fabric. Most of the minerals listed as accessories are genetically important and if present should be included in the rock name regardless of their quantity.

CLASSIFICATION OF METAMORPHIC ROCKS

By Russell B. Travis

DIRECTIONAL STRUCTURE (Lineate or Foliate)

Mechanical Metamorphism

Cataclastic

These rocks are formed by crushing and shearing with only minor recrystallization. If there are no conspicuous directional textures, the rock is called "crush breccias" if coarse grained, and "cataclasite" if fine grained. Most of them, however, are foliate.

MYLONITE—finely ground, foliate

FLASER GRANITE, FLASER DIORITE, FLASER CONGLOMERATE, ETC.—flaser structure

AUGEN GNEISS—augen structure

ULTRAMYLONITE—partially fused mylonite

Rocks with only minor deformation may be called "schistose," for example "schistose sandstone," "schistose shoales," etc., but these are not properly metamorphic rocks.

Regional Metamorphism

Slaty

Most slates are dark colored

SILTY SLATE
GREEN SLATE
BLACK SLATE
SPOTTED SLATE
ANDALUSITE SPOTTED SLATE
CHIASTOLITE SPOTTED SLATE
BIOTITE SPOTTED SLATE
CARBONACEOUS SLATE
CALCAREOUS SLATE

Phyllitic

PHYLLITE is intermediate between slate and schist. It differs from slate in that crystallization of micaceous minerals imparts a sheen to the rock; it differs from schist in that grains are too small for megascopic identification.

PHYLLONITE—a phyllite owing its fine grain to mylonitization

Schistose

QUARTZ-MICA SCHIST
TALC SCHIST
SILLIMANITE SCHIST
ALBITE-MICA SCHIST
QUARTZ-SERICITE SCHIST
KYANITE SCHIST
CALCITE SCHIST (Schistose marble)

MICA SCHIST
CHIASTOLITE SCHIST
ANDALUSITE SCHIST
STAUROLITE SCHIST
KYANITE SCHIST
PYROPHYLLITE SCHIST
GARNET-MICA SCHIST
SERPENTINE*
TOURMALINE-MICA SCHIST
ANTHOPHYLLITE SCHIST
STAUROLITE-KYANITE SCHIST
SILLIMANITE-GARNET SCHIST
GRAPHITE SCHIST
CALCITE SCHIST (Schistose marble)
SCHISTOSE QUARTZITE

GREENSCHIST
CHLORITE SCHIST
CHLORITOID SCHIST
GLAUCOPHANE SCHIST
AMPHIBOLITE (HORNBLENDE SCHIST)
ACTINOLITE SCHIST
GRAPHITE SCHIST
PYROXENE SCHIST
EPIDOTE-CHLORITE SCHIST
HORNBLENDE- BIOTITE SCHIST
BIOTITE-CHLORITE SCHIST
SERPENTINE*
TOURMALINE SCHIST
EPIDOTE AMPHIBOLITE
GARNET-PYROXENE AMPHIBOLITE
GARNET-CHLORITE SCHIST

Gneissose

RHYOLITE GNEISS
QUARTZ PORPHYRY GNEISS
QUARTZITE GNEISS
SILLIMANITE GNEISS
GRANULITE—banding due to elongated quartz or feldspar grains

GRANITE GNEISS
SYENITE GNEISS
MONZONITE GNEISS
GRANODIORITE GNEISS
ANORTHOSITE GNEISS
TRACHYTE GNEISS
CONGLOMERATE GNEISS
ARKOSE GNEISS
SANDSTONE GNEISS
AUGEN GNEISS—augen structure
BIOTITE GNEISS
STAUROLITE GNEISS
PLAGIOCLASE GNEISS
GARNET GNEISS
MUSCOVITE-BIOTITE-QUARTZ GNEISS
KYANITE GNEISS
GRANULITE—banding due to elongated quartz or feldspar grains

QUARTZ DIORITE GNEISS
DIORITE GNEISS
GABBRO GNEISS
PERIDOTITE GNEISS
DIABASE GNEISS
PYROXENE GNEISS
GRAYWACKE GNEISS
EPIDOTE GNEISS
GARNET-BIOTITE GNEISS
SKARN GNEISS
AMPHIBOLITE GNEISS

Plutonic Metamorphism

Migmatitic

These rocks have a gneissose, streaked, or irregular structure produced by intimate mixing of metamorphic and magmatic materials. When they can be recognized as "mixed rock," they are called *migmatite* or *migmatite gneiss*. They may originate by injection (injection migmatite, injection gneiss, or lit-par-lit gneiss), or by differential fusion. Many so-called migmatites probably originate by partial granitization or by metamorphic differentiation. But at great depth these processes apparently do not differ substantially from the igneous processes forming migmatite, so the products are usually indistinguishable.

Migmatites are named by prefixing the rock name of the granitic material to the appropriate root as "granite migmatite," "monzonite injection migmatite," etc.

* **SERPENTINE** is a product of hydrothermal alteration which some authorities consider to be an igneous process and others a metamorphic process. For this reason serpentine appears both on this chart and on the igneous rock chart.

FREQUENCY OF OCCURRENCE

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